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and Mines

**Aggregate Resources Inventory of
Logan and Hibbert Townships
Perth County**

Ontario Geological Survey
Aggregate Resources Inventory
Paper 111

By Staff of the Engineering and Terrain Geology Section,
Ontario Geological Survey, Ministry of Northern Development and
Mines

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Abstract

This report includes an inventory and evaluation of sand and gravel, as well as bedrock resources, in Logan and Hibbert townships. The report is part of the Aggregate Resources Inventory Program for townships and municipalities designated under the Aggregate Resources Act.

The aggregate resources in Logan and Hibbert townships are of variable quality and quantity. Generally, Logan Township has low possible resources of sand and gravel, which likely will be insufficient for local needs in the near future and will require augmentation from outside sources. The aggregate resources in Hibbert Township are generally of excellent quality and are suitable for the production of a wide range of road-building and general construction products. The main factor influencing the suitability of the aggregate, is the extremely variable nature of some of the deposits. The deposits may contain material which restricts high specification use of the aggregate. Generally, Hibbert Township contains potential resources which should supply local requirements for a considerable period of time.

Seven deposits containing sand and gravel have been selected for possible resource protection at the primary level. Four of the selected areas are ice-contact-esker deposits located in northwestern Logan Township. The remaining selected areas are ice-contact-kame deposits located in Hibbert Township. The

Primary Resource Areas constitute the most important natural aggregate sources in Logan and Hibbert townships. They have an area of 1360 acres (550 ha) available for extraction, containing possible reserves of 75 million tons (68 million tonnes) of sand and gravel. The parts of the selected areas which are available for extraction represent 32% of the total area of sand and gravel deposits in the townships and 40% of the original tonnage.

A number of outwash, esker, ice-contact, ice-contact-kame and ice-contact-esker deposits have been selected as Resource Areas of Secondary Significance. Although these secondary deposits are not considered the "best" resources, they should be considered part of the report area's total aggregate supply.

Most of Logan and Hibbert townships are overlain by more than 50 feet (15 m) of drift, although scattered areas of thinner drift do occur. Bedrock in the townships consists largely of limestone of the Amherstburg, Lucas and Dundee formations. The Dundee and Lucas formations may have value for use in crushed stone products, however, testing would be required to establish their suitability in these townships. For this reason, no areas have been selected for possible resource protection.

Selected Resource Areas are not intended to be permanent, single land use units. They represent areas where a major resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

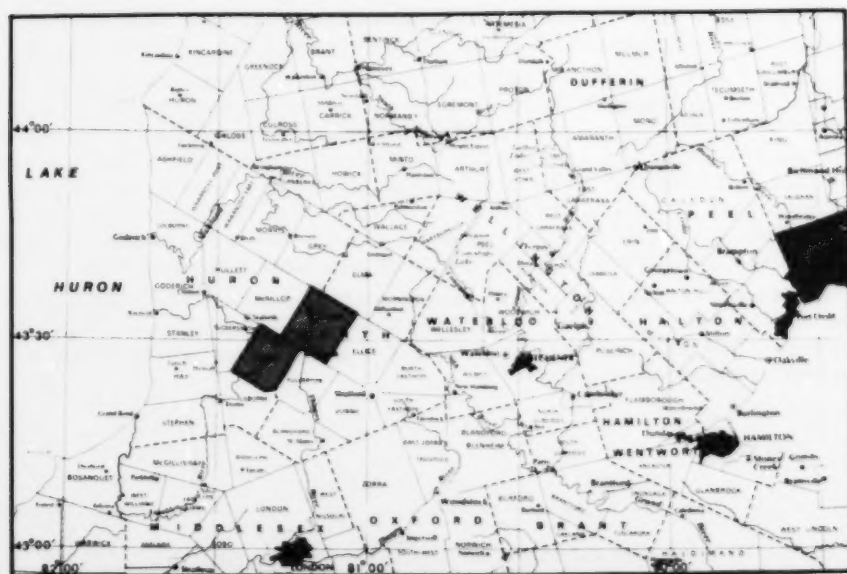


Figure 1. Key map showing the location of Logan and Hibbert townships, scale 1:1 800 000.

Résumé

Ce rapport comprend à la fois un inventaire et une estimation des ressources en sable et en gravier ainsi que des ressources du substratum rocheux des cantons de Logan et de Hibbert. Ce rapport fait partie du programme sur l'inventaire des ressources en agrégat pour les cantons et les municipalités désignés sous le régime de la Loi sur les ressources en agrégat.

Les ressources en agrégat dans les cantons de Logan et Hibbert sont de qualité et de quantité variable. D'une manière générale, le canton de Logan possède un faible potentiel de ressources possibles en sable et gravier, vraisemblablement insuffisant pour couvrir les besoins locaux dans le proche avenir et qui nécessitera un apport provenant de sources extérieures. Les ressources en agrégat du canton de Hibbert sont en général d'excellente qualité et conviennent pour de nombreux types de produits pour la construction routière et pour la construction en général. Le facteur principal susceptible de déterminer si l'agrégat convient est la nature extrêmement variable de certains dépôts. Les dépôts peuvent contenir des matériaux qui empêchent l'utilisation de l'agrégat pour des usages de haute spécification. Le canton de Hibbert possède un potentiel de ressources qui devrait satisfaire les besoins locaux pour de nombreuses années.

Sept dépôts contenant du sable et du gravier ont été choisis pour une éventuelle réserve de ressources de première importance. Quatre des zones choisies sont des dépôts de contact glaciaire-eskers dans le nord-ouest du canton de Logan. Les autres sont des dépôts de contact glaciaire-kames dans le canton de Hibbert. Les zones de ressources de première importance représentent les sources naturelles d'agrégat les plus importantes dans les cantons de Logan et de Hibbert. Elles occupent une superficie de 1360 acres (550 ha) disponible à l'extraction et contenant des réserves possibles de 75 millions de tonnes courtes (68 millions de tonnes métriques) de sable et de gravier. La portion des zones choisies disponible pour l'extraction représente 32% de la surface totale occupée par les dépôts de sable et de gravier dans les cantons et 40% du tonnage original.

Un nombre de dépôts d'épandage fluvio-glaciaire, d'esker, de contact glaciaire-kames et de contact glaciaire-eskers ont été sélectionnés en tant que zones de ressources d'importance secondaire. Bien que ces dépôts secondaires ne soient pas considérés comme étant les «meilleures» ressources, elles font néanmoins partie intégrante des réserves totales en agrégat dans le secteur couvert par le rapport.

Les cantons de Logan et de Hibbert sont en grande partie recouverts par une couche de dépôts glaciaires dépassant 50 pieds (15 m) d'épaisseur, bien qu'il y ait des endroits où le recouvrement est moins épais. Le substratum rocheux dans les cantons est formé surtout de calcaire appartenant aux formations de Amherstburg, de Lucas et de Dundee. Les formations de Lucas et de Dundee peuvent être intéressantes pour la fourniture des produits de pierre concassée, cependant des essais préalables seraient nécessaires afin d'établir leur mise en valeur dans ces cantons. Pour cette raison, aucune zone n'a été sélectionnée pour une protection possible des ressources.

Les zones de ressources sélectionnées ne sont pas destinées à un usage unique et permanent. Elles représentent des secteurs dans lesquels une ressource importante est reconnue et peut être réservée entièrement ou partiellement pour l'exploitation et/ou comme réserve de ressources.

Aggregate Resources Inventory of Logan and Hibbert Townships Perth County

By Staff¹ of the Engineering and Terrain Geology Section

1. Project Supervisor: I. Szoke; field work and report by R. Gorman and D.S. Tennant; compilation and drafting by Staff of the Aggregate Assessment Office. Assistance with review provided by the Resident Geologist of the Southwestern District of the Ministry of Northern Development and Mines. The Mineral Resources Staff of Wingham District Office and Southwestern Region of the Ministry of Natural Resources assisted in the collection of data, field checking and review of this report.

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Introduction

Mineral aggregates, which include bedrock-derived crushed stone as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road-building and construction industries. Very large amounts of these materials are used each year throughout the Province. For example, in 1987, the total tonnage of mineral aggregates extracted was 156 million tons (142 million tonnes), greater than that of any other metallic or nonmetallic commodity mined in the Province (Ontario Ministry of Northern Development and Mines 1989).

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, nonrenewable resources which can be exploited only in those areas where they occur. Mineral aggregates are characterized by their high bulk and low unit value so that the economic value of a deposit is a function of its proximity to a market area as well as its quality and size. The potential for extractive development is usually greatest in urban fringe areas where land use competition is extreme. For these reasons the availability of adequate resources for future development is now being threatened in some areas.

Comprehensive planning and resource management strategies are required to make the best use of

available resources, especially in those areas experiencing rapid development. Such strategies must be based on a sound knowledge of the total mineral aggregate resource base at both local and regional levels. The purpose of the Aggregate Resources Inventory is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies and official plans. The reports should form the basis for discussion on those areas best suited for possible extraction. The aim is to assist decision-makers in protecting the public well-being by ensuring that adequate resources of mineral aggregate remain available for future use.

This report is a technical background document, based for the most part on geological information and interpretation. It has been designed as a component of the total planning process and should be used in conjunction with other planning considerations, to ensure the best use of a municipality's resources.

The report includes an assessment of sand and gravel resources as well as a discussion on the potential of bedrock-derived aggregate. The most recent information available has been used to prepare the report. As new information becomes available, revisions may be necessary.

Part I — Inventory Methods

FIELD AND OFFICE METHODS

The methods used to prepare the report primarily involve the interpretation of published geological data such as bedrock and surficial geology maps and reports (see References) as well as field examination of potential resource areas. Field methods include the examination of natural and man-made exposures of granular material. Most observations are made at quarries and sand and gravel pits located from records held by the Ontario Ministry of Transportation, the Ontario Geological Survey, and by Regional and District Offices of the Ontario Ministry of Natural Resources. Observations made at pit sites include estimates of the total face height and the proportion of gravel- and sand-sized fragments in the deposit. Observations are also made of the shape and lithology of the particles. These characteristics are important in estimating the quality and quantity of the aggregate. In areas of limited exposure, subsurface materials may be assessed by hand augering and test pitting, supplemented by test hole drilling, and geophysical surveys using hammer seismic equipment. The symbols for and locations of sample sites, test hole sites, and geophysical traverse lines are noted on Map 1.

Deposits with potential for further extractive development or those where existing data are scarce, are studied in greater detail. Representative layers in these deposits are sampled in 25- to 100-pound (11 to 45 kg) units from existing pit faces or from test pits. The samples are analysed for grain size distribution, and in some cases absorption, Los Angeles abrasion, and Magnesium Sulphate soundness tests and petrographic analyses are carried out. Analyses are performed either in the laboratories of the Soils and Aggregates Section, Engineering Materials Office, Ontario Ministry of Transportation, or in the Geoscience Laboratory, Ontario Geological Survey.

The field data are supplemented by pit information on file with the Soils and Aggregates Section of the Ontario Ministry of Transportation. Data contained in these files include field estimates of the depth, composition and "workability" of deposits, as well as laboratory analyses of the physical properties and chemical suitability of the aggregate. Information concerning the development history of the pits and acceptable uses of the aggregate is also recorded. The location, size and depth of extraction of pits licenced under the Aggregate Resources Act are obtained from records held by Regional and District Offices of the Ontario Ministry of Natural Resources. The cooperation of the above-named groups in the compilation of inventory data is gratefully acknowledged.

Aerial photographs at various scales are used to determine the continuity of deposits, especially in areas where information is limited. Water well records, held by the Ontario Ministry of the Environment, are used in

some areas to corroborate deposit thickness estimates or to indicate the presence of buried granular material. These records are used in conjunction with other evidence.

Topographic maps of the National Topographic System, at a scale of 1:50 000, are used as a compilation base for the field and office data. The information is then transferred to a base map, also at a scale of 1:50 000. These base maps are prepared by the Surveys, Mapping and Remote Sensing Branch, Ontario Ministry of Natural Resources with information taken from maps of the National Topographic System by permission of Energy, Mines and Resources Canada, for presentation in the report.

RESOURCE TONNAGE CALCULATION TECHNIQUES

SAND AND GRAVEL RESOURCES

Once the interpretative boundaries of the aggregate units have been established, quantitative estimates of the possible resources available can be made. Generally, the volume of a deposit can be calculated if its areal extent and average thickness are known or can be estimated. The computation methods used are as follows. First, the area of the deposit, as outlined on the final base map, is calculated in acres. The thickness values used are an approximation of the deposit thickness, based on the face heights of pits developed in the deposit or on subsurface data such as test holes and water well logs. Original tonnage values can then be calculated by multiplying the volume of the deposit by 2500 (the density factor). This factor is approximately the number of tons in a one-foot (0.3 m) thick layer of sand and gravel, one acre (0.4 ha) extent, assuming an average density of 110 pounds per cubic foot (1766 kg/m³).

$$\text{Tonnage} = \text{Area} \times \text{Thickness} \times \text{Density Factor}$$

Tonnage calculated in this manner must be considered only as an estimate. Furthermore, such tonnages represent amounts that existed prior to any extraction of material (i.e., original tonnage) (Table 1, Column 4).

The Selected Sand and Gravel Resource Areas in Table 3 are calculated in the following way. Two successive subtractions are made from the total area. Column 3 accounts for the number of acres unavailable because of the presence of permanent cultural features and their associated setback requirements. Column 4 accounts for those areas that have previously been extracted (e.g., wayside and abandoned pits are included in this category). The remaining figure is the area of the deposit currently available for extraction (Column 5). The available area is then multiplied by the estimated deposit thickness and the density factor (Column 5 x Column 6 x 2500) to give an estimate of the sand and gravel tonnage

(Column 7) presently available for extractive development and/or resource protection.

Reserve estimates are calculated for deposits of primary significance. Reserve estimates for deposits of secondary and tertiary significance are not calculated in Table 3, however the aggregate potential of these deposits is discussed in the report.

BEDROCK RESOURCES

The method used to calculate resources of bedrock-derived aggregate is much the same as that described above. The areal extent of bedrock formations overlain by less than 50 feet (15 m) of unconsolidated overburden is determined from bedrock geology maps, drift thickness and bedrock topography maps, and from the interpretation of water well records. The measured extent of such areas is then multiplied by the estimated quarriable thickness of the formation, based on stratigraphic analyses and on estimates of existing quarry faces in the unit. In some cases a standardized estimate of 60 feet (18 m) is used for thickness. Volume estimates are then multiplied by the density factor [the estimated weight in tons of a one-foot (0.3 m) thick section of rock, one acre (0.4 ha) in extent].

Resources of dolostone are calculated using a density factor of 165 pounds per cubic foot (2649 kg/m^3) or 3600 tons per acre (8070 t/ha). Sandstone resources are calculated using a density estimate of 146 pounds per cubic foot (2344 kg/m^3) and shale resources are calculated with a factor of 150 pounds per cubic foot (2408 kg/m^3).

UNITS AND DEFINITIONS

Although most of the measurements and other primary data available for resource tonnage calculations are given in Imperial units, Metric units have also been given in the text and on the tables which accompany the report. The Metric equivalent of the data is shown in brackets after or directly below the corresponding Imperial figures. Data are generally rounded off in accordance with the Ontario Metric Practice Guide (Metric Committee 1975).

The tonnage estimates made for sand and gravel deposits are termed possible resources (see Glossary, Appendix B) in accordance with terminology of the Ontario Resource Classification Scheme (Robertson 1975, p.7) and with the Association of Professional Engineers of Ontario (1976).

Part II — Data Presentation and Interpretation

Three maps, each portraying a different aspect of the aggregate resources in the municipality, accompany the report. Map 1, "Distribution of Sand and Gravel Deposits", gives a comprehensive inventory of the sand and gravel resources in the report area. Map 2, "Selected Sand and Gravel Resource Areas", shows those deposits which are considered to represent the largest and/or highest quality resources in the area. Map 3, "Bedrock Resources" shows the distribution of bedrock formations, the thickness of overlying unconsolidated sediments, and identifies the Selected Bedrock Resource Areas.

MAP 1: DISTRIBUTION OF SAND AND GRAVEL DEPOSITS

Map 1 is derived from existing surficial geology maps of the area or from aerial photograph interpretation in areas where surficial mapping is incomplete. The map shows the extent and quality of sand and gravel deposits within the study area and the present level of extractive activity.

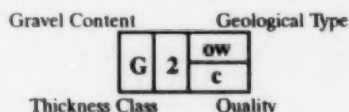
On the map, gravel deposits are indicated by dark brown shading while sand deposits are shaded light brown. The present level of extractive activity is also indicated. Those areas which are licenced for extraction under the Aggregate Resources Act are shown by a solid outline and identified by a number which refers to the pit descriptions in Table 2. Each description notes the owner/operator, location and licenced acreage of the pit, as well as the estimated face height and percentage gravel. A number of unlicensed pits (abandoned pits or wayside pits operating on demand under authority of a permit) are identified by a numbered dot on Map 1 and described in Table 2. Similarly, test hole locations appear on Map 1 as a point symbol and are described in Table 7. Geophysics lines are shown on Map 1 by a line symbol and are interpreted in Table 8.

Map 1 also presents a summary of available information related to the quality of aggregate contained in all the known aggregate deposits in the study area. Much of this information is contained in the symbols which are found on the map. The Deposit Symbol appears for each mapped deposit and summarizes important genetic and textural data. The Texture Symbol is a circular proportional diagram which displays the grain size distribution of the aggregate in areas where bulk samples were taken.

DEPOSIT SYMBOL

The Deposit Symbol is similar to those used in soil mapping and land classification systems commonly in use in North America. The components of the symbol indicate the gravel content, thickness of material, origin (type) and quality limitations for every deposit shown on Map

1. These components are illustrated by the following example:



This symbol identifies an outwash deposit 10 to 20 feet (3 to 6 m) thick containing more than 35% gravel. Excess silt and clay may limit uses of the aggregate in the deposit.

The "gravel content" and "thickness class" are basic criteria for distinguishing different deposits. The "gravel content" symbol is an upper case "S" or "G". The "S" indicates that the deposit is generally "sandy" and that gravel-sized aggregate (greater than 4.75 mm) makes up less than 35% of the whole deposit. "G" indicates that the deposit contains more than 35% gravel.

The "thickness class" indicates a depth range which is related to the potential resource tonnage for each deposit. Four thickness class divisions have been established as shown in the legend for Map 1.

Two smaller sets of letters, divided from each other by a horizontal line, follow the thickness class number. The upper series of letters identifies the geologic deposit type (the deposit types are summarized with respect to their main geologic and extractive characteristics in Appendix C) and the lower series of letters identifies the main quality limitations that may be present in the deposit as discussed in the next section.

TEXTURE SYMBOL

The Texture Symbol provides a more detailed assessment of the grain size distribution of material sampled during field study. These symbols are derived from the information plotted on the aggregate grading curves found in the report. The relative amounts of gravel, sand, and silt and clay in the sampled material are shown graphically in the Texture Symbol by the subdivision of a circle into proportional segments. The following example shows a hypothetical sample consisting of 30% gravel, 60% sand and 10% silt and clay:



MAP 2: SELECTED SAND AND GRAVEL RESOURCE AREAS

Map 2 is an interpretative map derived from an evaluation of the deposits shown on Map 1. The deposits identified on Map 2 are those which are considered to be im-

portant in ensuring an adequate resource base for the future.

All the selected sand and gravel resource areas are first delineated by geological boundaries and then classified into three levels of significance: primary, secondary and tertiary. Each area of primary significance is given a deposit number and all such deposits are shown by dark red shading on Map 2.

Selected Sand and Gravel Resource Areas of primary significance are not intended to be permanent, single land use units. They represent areas in which a major resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

Deposits of secondary significance are indicated by light red shading on Map 2. Such deposits are believed to contain significant amounts of sand and gravel. Although deposits of secondary significance are not considered to be the "best" resources in the report area, they may contain large quantities of sand and gravel and should be considered as part of the aggregate supply of the area.

Areas of tertiary significance are outlined on the map by a solid line but have no shading. They are not considered to be important resource areas because of their low available resources, or because of possible difficulties in extraction. Such areas may be useful for local needs but are unlikely to support large-scale development.

The process by which deposits are evaluated and selected involves the consideration of two sets of criteria. The main selection criteria are site specific, related to the characteristics of individual deposits. Factors such as deposit size, aggregate quality, and deposit location and setting are considered in the selection of those deposits best suited for extractive development. A second set of criteria involves the assessment of local aggregate resources in relation to the quality, quantity, and distribution of resources in the region in which the report area is located. The intent of such a process of evaluation is to ensure the continuing availability of sufficient resources to meet possible future demands.

SITE SPECIFIC CRITERIA

Deposit Size

Ideally, selected deposits should contain available sand and gravel resources large enough to support a commercial pit operation using a stationary or portable processing plant. In practice, much smaller deposits may be of significant value depending on the overall reserves in the rest of the municipality. Generally, deposits in Class 1 [greater than 20 feet (6 m) thick] and containing more than 35% gravel are considered to be most favourable for commercial development. Thinner deposits may be valuable in municipalities with low total resources.

Aggregate Quality

The limitations of natural aggregates for various uses result from variations in the lithology of the particles composing the deposit, and from variations in the size distribution of these particles.

Four indicators of the quality of aggregate may be included in the deposit symbols on Map 1. They are: gravel content (G or S), fines (C), oversize (O) and lithology (L).

Three of the quality indicators deal with grain size distribution. The gravel content (G or S) indicates the suitability of aggregate for various uses. Deposits containing at least 35% gravel in addition to a minimum of 20% material greater than the 26.5 mm sieve are considered to be the most favourable extractive sites, since this content is the minimum from which crushed products can be economically produced.

Excess fines (high silt and clay content) may severely limit the potential use of a deposit. Fines content in excess of 10% may impede drainage in road subbase aggregate and render it more susceptible to the effects of frost action. In asphalt aggregate, excess fines hinder the bonding of particles. Deposits known to have a high fines content are indicated by a "C" in the quality portion of the Deposit Symbol.

Deposits containing more than 20% oversize material [greater than 4 inches (10 cm) in diameter] may also have use limitations. The oversize component is unacceptable for all concrete aggregate and for road-building aggregate, so it must be either crushed or removed during processing. Deposits known to have an appreciable oversize component are indicated by an "O" in the quality portion of the Deposit Symbol.

Another indicator of the quality of an aggregate is lithology. Just as the unique physical and chemical properties of bedrock types determine their value for use as crushed rock, so do various lithologies of particles in a sand and gravel deposit determine its suitability for various uses. The presence of objectionable lithologies such as chert, siltstone and shale, even in relatively small amounts, can result in a reduction in the quality of an aggregate, especially for high quality uses such as concrete and asphalt. Similarly, highly weathered, very porous and friable rock can restrict the quality of an aggregate. Deposits known to contain objectionable lithologies are indicated by an "L" in the quality component of the Deposit Symbol.

If the Deposit Symbol shows either "C", "O", or "L" or any combination of these indicators, the quality of the deposit is considered to be reduced for some uses of the aggregate. No attempt is made to quantify the degree of limitation imposed. Assessment of the four indicators is made from published data, from data contained in files of both the Ontario Ministry of Transportation and the Engineering and Terrain Geology Section of the Ontario Geological Survey, and from field observations.

Quality data may also appear in Table 9, where the results of aggregate quality tests are listed by test type and sample location. The types of tests conducted and

the test specifications are explained in Appendixes B and E, respectively.

Analyses of unprocessed samples obtained from test holes, pits or sample sites are plotted on grain size distribution graphs. On the graphs are the Ontario Ministry of Transportation's gradation specification envelopes for aggregate products: Granular Base Course A, B and C, Hot-Laid Asphaltic Sand Nos. 1,2,3,4 and 8, and concrete sand. By plotting the gradation curves with respect to the specification envelopes, it can be determined how well the unprocessed sampled material meets the criteria for each product. These graphs, called Aggregate Grading Curves, follow the tables in the report.

Location and Setting

The location and setting of a resource area has a direct influence on its value for possible extraction. The evaluation of a deposit's setting is made on the basis of natural and man-made features which may limit or prohibit extractive development.

First, the physical context of the deposit is considered. Deposits with some physical constraint on extractive development, such as thick overburden or high water table, are less valuable resource areas because of the difficulties involved in resource recovery. Second, permanent man-made features, such as roads, railways, powerlines, and housing developments, which are built on a deposit, may prohibit its extraction. The constraining effect of legally required setbacks surrounding such features is included in the evaluation. A quantitative assessment of these constraints can be made by measurement of their areal extent directly from the topographic maps. The area rendered unavailable by these features is shown for each resource area in Table 3 (Column 3).

The assessment of sand and gravel deposits with respect to local land use and to private land ownership is an important component of the general evaluation process. These aspects of the evaluation process are not considered further in this report, but readers are encouraged to discuss them with personnel of the pertinent District Office of the Ontario Ministry of Natural Resources.

REGIONAL CONSIDERATIONS

In selecting sufficient areas for resource development, it is important to assess both the local and the regional resource base, and to forecast future production and demand patterns.

Some appreciation of future aggregate requirements in an area may be gained by assessing its present production levels and by forecasting future production trends. Such an approach is based on the assumptions that production levels in an area closely reflect the demand and that the present production "market share" of an area will remain roughly at the same level.

The aggregate resources in the region surrounding a municipality should be assessed in order to properly evaluate specific resource areas and to adopt optimum resource management plans. For example, a municipality that has large resources in comparison to its surrounding region constitutes a regionally significant resource area. Municipalities with high resources in proximity to large demand centres, such as metropolitan areas, are special cases.

Although an appreciation of the regional context is required to develop comprehensive resource management techniques, such detailed evaluation is beyond the scope of this report. The selection of resource areas made in this study is based primarily on geological data or on considerations outlined in preceding sections.

MAP 3: BEDROCK RESOURCES

Map 3 is an interpretative map derived from bedrock geology, drift thickness and bedrock topography maps, water well data from the Ontario Ministry of the Environment, oil and gas well data from the Petroleum Resources Section (Ontario Ministry of Natural Resources) and from geotechnical test hole data from various sources. Map 3 is based on concepts similar to those outlined for Maps 1 and 2, but displays both the inventory and evaluation on the one map.

The geological boundaries of the bedrock units are shown by a dashed line. Isolated outcrops are indicated by an "X". Three sets of contour lines delineate areas of less than 3 feet (1 m) of drift, areas of 3 to 25 feet (1 to 8 m) of drift, and areas of 25 to 50 feet (8 to 15 m) of drift. The extent of these areas of thin drift are shown by three shades of blue. The darkest shade indicates where bedrock outcrops or is within 3 feet (1 m) of the ground surface. These areas constitute potential resource areas because of their easy access. The medium shade indicates areas where drift cover is up to 25 feet (8 m) thick. Quarrying is possible in this depth of overburden and these zones also represent potential resource areas. The lightest shade indicates bedrock areas overlain by 25 to 50 feet (8 to 15 m) of overburden. These latter areas constitute resources which have extractive value only in specific circumstances. Outside of these delineated areas, the bedrock can be assumed to be covered by more than 50 feet (15 m) of overburden, a depth generally considered to be too great to allow economic extraction (unless part of the overburden is composed of economically attractive deposits).

Other inventory information presented on Map 3 is designed to give an indication of the present level of extractive activity in the report area. Those areas which are licenced for extraction under the Aggregate Resources Act are shown by a solid outline and identified by a number which refers to the quarry descriptions in Table 5. Each description notes the owner/operator, location, licenced acreage and an estimate of face height. Unlicenced quarries (abandoned quarries or wayside quarries operating on demand under authority of a permit) are also identified and numbered on Map 3 and de-

scribed in Table 5. Two additional symbols may appear on the map. An open dot indicates the location of a selected water well which penetrates bedrock. The overburden thickness is shown in feet beside the open dot. Similarly, test hole locations appear as a point symbol with the depth to bedrock shown in feet beside it. The test holes may be further described in Table 7.

SELECTION CRITERIA

Criteria equivalent to those used for sand and gravel deposits are used to select bedrock areas most favourable for extractive development.

The evaluation of bedrock resources is made primarily on the basis of performance and suitability data established by laboratory testing at the Ontario Ministry of Transportation. The main characteristics and uses of the bedrock units found in southern Ontario are summarized in Appendix D.

Deposit "size" is related directly to the areal extent of thin drift cover overlying favourable bedrock formations. Since vertical and lateral variations in bedrock units are much more gradual than in sand and gravel deposits, the quality and quantity of the resource are usually consistent over large areas.

Quality of the aggregate derived from specific bedrock units is established by the performance standards previously mentioned. Location and setting criteria and regional considerations are identical to those for sand and gravel deposits.

SELECTED RESOURCE AREAS

Selection of Bedrock Resource Areas has been restricted to a single level of significance. Three factors support this approach. First, quality and quantity variations are gradual. Second, the areal extent of a given quarry operation is much smaller than that of a sand and gravel pit producing an equivalent tonnage of material, and third, since crushed bedrock has a higher unit value than sand and gravel, longer haul distances can be considered. These factors allow the identification of alternative sites having similar development potential. The Selected Areas, if present, are shown on Map 3 by a line pattern and the calculated available tonnages are given in Table 6.

Selected Bedrock Resource Areas shown on Map 3 are not permanent, single land use units. They represent areas in which a major bedrock resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

Part III - Assessment of Aggregate Resources in Logan and Hibbert Townships

LOCATION AND POPULATION

Logan and Hibbert townships occupy 98 814 acres (39 990 ha) in western Perth County, southwestern Ontario. The townships are shown at a scale of 1:50 000 on the Seaforth (40 P/11) and St. Marys (40 P/6) map sheets of the National Topographic System.

The population of Logan Township was greatest at the end of the nineteenth century and has steadily declined since then. Increased farm size and mechanization contributed greatly to this trend. However, in recent years the rate of decline has slowed down. In the period from 1982 to 1985, the population decreased 2% to reach 2149 (Ontario Ministry of Municipal Affairs and Housing 1983; Ontario Ministry of Municipal Affairs 1988). Historically, Hibbert Township has also experienced a similar decline in population. From 1982 to 1985, however, the trend changed and the population increased 2% to reach 1391 (Ontario Ministry of Municipal Affairs and Housing 1983; Ontario Ministry of Municipal Affairs 1988).

The majority of the townships' inhabitants are rural-residential or rural-farm residents. Agriculture is the dominant land use and economic activity in the townships. Good soils and climatic conditions combine to make it a viable mixed farming area.

The town of Mitchell is located along the southwestern boundary of Logan Township. The population of the town has increased slowly to 2947 in 1985 (Ontario Ministry of Municipal Affairs 1988). The town is a local market and service centre for the surrounding agricultural communities and contains a number of secondary manufacturing industries. In addition, local residential and service centres including the unincorporated village of Monkton and several hamlets, such as Bornholm, Brodhagen, Dublin, Staffa, Cromarty and St. Columban, are situated within the townships. Outside of the townships, the city of Stratford and the towns of Seaforth and Exeter also provide major commercial, industrial and institutional services.

The townships are accessible by King's highways 8, 23 and 83, and by various county and township roads. Railway service is provided by one Canadian National Railways line which runs parallel to, and south of, King's Highway 8. This freight line links Goderich and Stratford.

PHYSIOGRAPHY AND SURFICIAL GEOLOGY

Approximately 23 000 years ago during the Late Wisconsinan Substage of the Pleistocene Epoch (informally known as the "Great Ice Age"), lobes or submasses of the Laurentide continental ice sheet advanced out of

the basins of the Great Lakes and joined together to cover southern Ontario. The lateral extent of the ice lobes and the positions of their margins underwent numerous fluctuations until approximately 10 000 years ago when the ice finally melted back and completely disappeared. The physiography and distribution of the surficial materials in Logan and Hibbert townships, and specifically the sand and gravel deposits shown on Maps 1 and 2 of this report, are the result of the activities of the Georgian Bay and Lake Huron ice lobes.

Logan and Hibbert townships are located predominantly within the physiographic region known as the Stratford Till Plain (Chapman and Putnam 1984). The plain is an area of gently undulating to flat ground moraine which slopes gently to the southwest. It is traversed by several terminal moraines, and has been extensively modified by glaciolacustrine silt and clay sedimentation. In Logan Township, the Stratford Till Plain is composed of two surficial till sheets separated from one another by the Mitchell Moraine (Taylor 1913). The Moraine trends roughly south through the township, just west and basically parallel to the North Thames River. In southwestern Hibbert Township the continuity of the till plain is interrupted by three low, but prominent, end moraine ridges that are subparallel to the Lake Huron shoreline and form part of the Horseshoe Moraines system (Chapman and Putnam 1984). These features are called the Dublin Moraine (Karrow 1977) and the Lucas and Seaforth moraines, respectively (Taylor 1913).

The Georgian Bay lobe advanced into the area in a southeasterly direction for the last time, approximately 14 000 years BP (Cooper et al. 1977). During this advance, Elma Till was deposited at the base of the ice lobe. Elma Till is a hard stony sandy silt till which is generally unsuitable for use as aggregate because it contains excessive amounts of fines. It forms the surface till east of the Mitchell Moraine and is found in the subsurface west of the moraine (Cooper et al. 1977).

As the Georgian Bay lobe melted back through the area, two esker complexes were deposited in Logan Township. The largest of these is located in the northwestern and central parts of the township, and extends north into Grey Township (Huron County). It is made up of several deposits which are composed of a semi-continuous esker core surrounded by undifferentiated ice-contact stratified drift. The esker core generally contains fine to coarse gravel, cobbles and boulders. The ice-contact sediments are composed mainly of very fine gravel, sand and silt. These deposits have been extensively worked in the past and are the most significant sources of aggregate in Logan Township.

The second esker complex, deposited during the melting of the Georgian Bay lobe, is located in northeastern Logan Township. This complex is much smaller

than the first one and has extremely subdued relief. The complex trends southeast from Monkton into neighbouring Ellice Township.

The Georgian Bay lobe continued to melt back and the Huron lobe advanced from the west, depositing Rannoch Till over the Elma Till (Cooper et al. 1977). The Rannoch Till is a compact to loose, moderately stony, silt to sandy silt till (Cooper et al. 1977). The Huron lobe advanced as far as the Mitchell Moraine which marks the easternmost limit of the Rannoch Till.

After forming the Mitchell Moraine the Huron lobe melted back, depositing esker, ice-contact, ice-contact-esker and ice-contact-kame sediments in Logan and Hibbert townships. The longest esker is known as the Mitchell Esker (Karrow 1977). The Mitchell Esker trends in an easterly direction from just east of Dublin in Hibbert Township, through into Logan Township, and is paralleled by a shorter esker to the south. These eskers have been extensively worked in the past and have proven to be valuable sources of sand and gravel. The eastern tip of an ice-contact-esker deposit is found along the western border of Logan Township, just west of Brodhagen.

During the melting of the Huron lobe, ice-contact-kames were deposited in Hibbert Township. The largest and most prominent ice-contact-kames are part of the Staffa kame complex. The Staffa kames formed in a small re-entrant in the ice-front (Karrow 1977), in contact with melting ice. The resulting kames are extensive hummocky hills composed of variable amounts of gravel, sand, silt, clay and till. These kame deposits are the largest source of sand and gravel in Hibbert Township.

The drainage of meltwaters from the Georgian Bay and the Huron ice lobes resulted in the formation of outwash and glaciolacustrine deposits in the two townships. An outwash fan to the northeast of Staffa in Hibbert Township was formed in a re-entrant in the Dublin Moraine (Karrow 1977). A wide range of aggregate products have been supplied from pits established within this fan deposit. A number of small outwash terraces are located along the North Thames River, northwest of Mitchell in Logan Township. Although these deposits may contain quality aggregate, their small size and past extraction limit their significance as aggregate sources. Glaciolacustrine sediments cover the till plain in many areas within the townships. These deposits were formed in slow moving or stationary waters during the short-lived period of glaciolacustrine ponding (Karrow 1977). The lake plains contain fine-grained sediment, predominantly silt with clay and minor sand. Their fine texture makes them unsuitable for use as aggregate, but clay has been extracted for brick manufacture from two shallow pits south of Dublin (Baker 1906; Keele 1924). A deposit in a shallow basin north of Brodhagen may be suitable for use in the clay products industry (Guillet 1967).

Postglacial erosional and depositional processes have been of minor importance in modifying the physiography of Logan and Hibbert townships.

EXTRACTIVE ACTIVITY

In 1981, Logan and Hibbert townships were designated under the Pits and Quarries Control Act and are now designated under the Aggregate Resources Act. Prior to that time, a number of pits had been operating on a casual basis throughout both townships. Many of these pits are now inactive, overgrown or rehabilitated. Thirty-three of the 63 pits identified in the townships have been rated by the Ontario Ministry of Transportation (MTO) on their ability to supply road-building and construction materials. Approximately three-quarters of the pits received "moderate" to "moderate-high" pit use ratings and were capable of producing Granular Base Course (GBC) A, and in many cases, Hot-Laid (HL) No. 4 asphaltic stone. The remaining sources received "low" ratings, and were capable of supplying GBC B and C (Deike 1982).

There are currently 16 pits in the report area licenced for extraction under the Aggregate Resources Act. The 5 licenced properties in Logan Township have a total area of 291.5 acres (118.0 ha), while the 11 licenced properties in Hibbert Township have a total area of 673.91 acres (272.73 ha). Since the designation of the townships, total production figures for licenced sources have been compiled annually by the Wingham District Office of the Ontario Ministry of Natural Resources. The average annual production over the seven-year period from 1982 to 1988 was 49 445 tons (44 950 tonnes) in Logan Township and 76 786 tons (69 806 tonnes) in Hibbert Township.

Aggregate production in Logan Township is aimed primarily at meeting the local demand (Phillips Planning and Engineering Ltd. 1972). Extensive past extraction has depleted a considerable amount of the township's resources of readily available good quality aggregate. Much of the remaining quality material is located below the water table and draglining or pumping would be necessary for extraction.

Hibbert Township has significant aggregate resource potential. The estimated granular resources should be sufficient to meet local demands in the immediate future. However, with some neighbouring townships relatively aggregate deficient, the demand on the aggregate resources in Hibbert Township may increase, possibly jeopardizing its ability to meet local demands.

SELECTED SAND AND GRAVEL RESOURCE AREAS

Map 1 indicates the deposits which contain granular materials. In Logan Township, granular deposits cover 1340 acres (540 ha) and contain an approximate resource tonnage of 51 million tons (46 million tonnes). In Hibbert Township, the total extent of these deposits is ap-

proximately 2850 acres (1150 ha), representing an original tonnage of 134 million tons (122 million tonnes). Many of the deposits have limited value for reasons of size, thickness or quality of the material. Consequently, only the most significant sources are suggested for possible resource protection at the primary level.

In Logan Township, an estimated 410 acres (166 ha) in the Primary Resource Areas are considered to be available for extraction, containing approximately 17 million tons (15 million tonnes) of aggregate. These figures represent 31% of the total area of sand and gravel deposits in the township, and 36% of the total tonnage. The Primary Resource Areas in Hibbert Township cover approximately 1220 acres (495 ha), exclusive of licenced properties. An estimated 950 acres (385 ha) are considered to be available for extraction, containing approximately 58 million tons (53 million tonnes) of sand and gravel. The available portions of these Resource Areas represent 33% of the total area of sand and gravel deposits in Hibbert Township, and 43% of the total tonnage.

Escher, ice-contact, ice-contact-kame, ice-contact-esker and glaciofluvial outwash deposits scattered throughout the townships have been designated for secondary resource protection. The secondary deposits serve as important alternate extraction sites, and should be considered part of the total aggregate supply.

Aggregate suitability data obtained from MTO indicate that generally, the pits identified within the resource areas contain aggregate of a hard and durable nature. In Logan Township available crushable gravel is definitely lacking, however, the amount of crushable gravel available in most pits in Hibbert Township is satisfactory. Workability problems common to both townships include the presence of coarse sand and fines. Coarse sand is unstable in many aggregate mixes (Deike 1982). A high fines content was noted in a number of pits in the townships, and limits aggregate use.

Channel face samples, taken in the licenced properties in both townships by staff members of the Wingham District Office of the Ontario Ministry of Natural Resources, were analysed for grain size distribution, soundness, absorption and lithology by the Materials Testing Laboratories of the Soils and Aggregates Section of the Ministry of Transportation, London, Ontario. The results of the tests on these samples are shown in Table 9. Granular base course petrographic numbers ranged from 100.0 to 163.3, indicating that, with the exception of one sample, the gravel quality in the samples was generally good and petrographically suitable for use in granular base course and 16 mm crushed stone products. The hot-mix and concrete petrographic numbers ranged from 108.3 to 208.2. Some of the petrographic numbers were borderline to unacceptable in terms of asphalt paving and structural concrete specifications. Unacceptable values may be attributed to the presence of undesirable materials such as chert, which originates from the underlying Dundee Formation. Although the presence of chert is not a major problem within the re-

port area, in some places it does occur in objectionable quantities. Aggregate quality with respect to chert content may be improved by selective extraction within a particular pit and/or by crushing oversize material and adding it to the aggregate in order to dilute the chert to acceptable levels (Deike 1982).

The percentage of crushable gravel in many of the deposits in Logan Township may be insufficient to meet the specifications for hot-laid asphaltic aggregate, structural concrete aggregate and, in some cases, GBC A (Deike 1982). The main sources of crushable gravel in Logan Township are the esker cores of the ice-contact-esker deposits. These often contain high concentrations of very coarse gravel, cobbles and boulders. This material is generally wear resistant and chert free, and therefore ideal for the production of high quality crushed gravel (Deike 1982). However, the esker cores have been extensively extracted in the past and much of the remaining material is located below the water table. Most of the sources open within the resource areas of Hibbert Township are capable of supplying gravel suitable for use in hot-mix asphalt and structural concrete (Deike 1982).

Magnesium Sulphate Soundness and Absorption tests were also performed on the licenced pit samples. The results of the Magnesium Sulphate Soundness test are expressed as a percent weight loss, whereas the results of the test for absorption are expressed as percent weight gained. The maximum allowable gains and losses, as well as the maximum allowable petrographic numbers of the various types of aggregate are shown in Appendix E.

The percent weight loss during the Magnesium Sulphate Soundness test for the coarse fraction of the samples was 1.8 to 11.9, which is within the ranges for most products. Similar weight loss results were obtained for the fine fraction of the sampled aggregate with only minor exceptions. When subjected to Absorption testing, samples taken from the townships had weight gains of 1.10 to 1.98%, which are acceptable for HL 4 and 8 concrete products, and in many cases HL 3 asphaltic aggregate. Los Angeles Abrasion test data from MTO indicate percent losses which meet the specifications for most products (Deike 1982).

LOGAN TOWNSHIP

Selected Sand And Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 is the northernmost deposit in the ice-contact-esker complex located in northwestern Logan Township. A large part of the deposit is currently licenced for extraction. The deposit has an unlicenced acreage of approximately 120 acres (49 ha).

Licenced pit nos. 1, 2 and 3 along with unlicenced pit no. 17 have been opened in Selected Resource Area 1. Past extraction has been largely centred on two esker segments which at one time were visible above the

ice-contact stratified drift. These eskers generally contained higher concentrations of gravel than the surrounding ice-contact sediments, and most of the esker material above the water table has been extracted. Draglining or pumping procedures would be required to extract the remaining esker material.

Faces in pits opened in the deposit ranged in height from 5 to 15 feet (1.5 to 5 m). The esker material exposed in the pits contained considerable quantities of coarse gravel and large oversize clasts. The oversize material should be removed or crushed in a primary crusher. The ice-contact stratified drift, which is the dominant material exposed in the pits, generally consists of sand, fine gravel and variable amounts of silt. Six samples were taken from the pits, and gravel contents in the samples ranged from 10.1 to 59.5% (Figures 2a and 3a). The fines content in one sample from pit no. 1 and the sample from pit no. 2 were too high for most aggregate uses. Test hole LG-TH-1, placed in the ice-contact sediments in licenced pit no. 1, uncovered 10 feet (3 m) of silty fine sand to silt with minor amounts of fine gravel. A sample of this material also revealed an excessive fines content (Figure 11a). The presence of silt seams and pockets in Resource Area 1 would necessitate selective extraction procedures. Up to 4 feet (1.2 m) of till overlies the aggregate in pit no. 1.

According to MTO data, the material exposed in the pits was suitable for use as granular base course and 16 mm Crushed Type B (Deike 1982). In addition, the aggregate in pit no. 1 was rated as being acceptable for 16 mm Crushed Type A and some asphaltic stone uses. Since most of the crushable gravel that was concentrated in the esker segments has been previously extracted or lies below the water table, only limited quantities of high-specification aggregate may be available. The deposit does contain considerable resources of aggregate suitable for local pit-run uses (Deike 1982).

After considering previous extraction and cultural constraints, the area available for extraction in Resource Area 1 is estimated to be 60 acres (24 ha). Based on an average thickness of 20 feet (6 m) of usable material, the deposit contains approximately 3 million tons (3 million tonnes) of aggregate. The deposit is easily accessible from various county and township roads.

Selected Sand And Gravel Resource Area 2

Selected Sand and Gravel Resource Area 2 is also part of the ice-contact-esker complex located in northwestern Logan Township. The deposit occupies 100 acres (40 ha), exclusive of licenced properties. Two pits have been developed in the Resource Area.

At the time of investigation, licenced pit no. 4 had 5- to 15-foot (1.5 to 5 m) faces and contained variable amounts of gravel. In the southern end of the pit a dragline was excavating between 10 and 15 feet (3 and 5 m) of esker material from below the water table. Gravel and oversize clasts were excavated and fed into a portable

crusher to produce GBC A and clear stone (predominantly a one-size construction aggregate). To the north, faces exposed mainly sand, and one face revealed 5 to 10 feet (1.5 to 3 m) of glaciolacustrine sand, silt and clay overlying 5 feet (1.5 m) of ice-contact sand. According to MTO data, the pit contained 0 to 75% gravel. A sample taken from this pit contained 59.4% gravel (Figure 4a, Pit 4b). The gravel quality was good and the pit has been rated as being able to produce granular base course, 16 mm Crushed Type B, and asphaltic sand with blending, however, most of the gravel has been removed above the water table. An additional sample contained no gravel and appears suitable for GBC C (Figure 4a, Pit 4a).

MTO data indicate that pit no. 5 had 20- to 25-foot (6 to 8 m) faces (Deike 1982). Coarse aggregate occurs in the northern eskerine sections of the pit, while sandy material occurs to the east and south in the ice-contact part of the pit. The sandy material was sampled and contained 4.1% gravel, 91.4% sand and 4.5% fines (Figure 4a). The limited amounts of good quality material exposed in the pit have similar use capabilities as that in pit no. 4. Oversize clasts are present in the pit and should be removed or crushed. A lack of binder may be a problem when the oversize material is crushed.

An available area of 80 acres (32 ha) has been estimated for Resource Area 2. Assuming an average deposit thickness of 20 feet (6 m), sand and gravel resources are approximately 4 million tons (4 million tonnes). The Resource Area is easily accessible from various county and township roads.

Selected Sand And Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 is the southernmost deposit in the ice-contact-esker complex in northwestern Logan Township. The Area occupies approximately 230 acres (93 ha) and one pit has been developed in it.

Abandoned pit no. 18 has been developed in an esker segment within the deposit. When investigated in the field, the pit was water filled and served as a small lake in a trailer park. However, MTO data obtained when the pit was operational indicated that the pit once had 10- to 25-foot (3 to 8 m) faces and contained 5 to 60% gravel. MTO has rated the pit as being able to produce material which is suitable for use in granular base course and 16 mm Crushed Type B (Deike 1982) but which is unacceptable for hot-laid and concrete uses. Test hole LG-TH-2 was drilled south of pit 18. Eleven feet (3 m) of coarse sand and fine gravel with fine to medium sand and some silt were encountered in the test hole.

After considering cultural constraints and previous extraction, Selected Resource Area 3 contains an estimated 205 acres (83 ha) available for extraction. Assuming a deposit thickness of 15 feet (5 m), the Resource Area contains approximately 8 million tons (7 million tonnes) of sand and gravel. The deposit is easily accessible by the existing road network.

Selected Sand And Gravel Resource Area 4

Selected Sand and Gravel Resource Area 4 is part of an ice-contact-esker deposit which is situated along the western boundary of Logan Township. The deposit also extends westward into McKillop Township (Huron County). The area of the deposit in Logan Township is approximately 77 acres (31 ha).

There are currently no pits opened in Resource Area 4 in Logan Township, but a number of pits have been developed in McKillop Township. A small pit is located directly west of the boundary between the townships. When it was investigated in the field it had a 10-foot (3 m) face and it was partially overgrown and slumped. Fine to coarse gravel, sand and silt were observed in the pit. MTO data for two pits located further west along the esker indicate that they have 5- to 20-foot (1.5 to 6 m) faces and contain 5 to 85% gravel. The pits are rated by MTO as being able to produce granular base course, 16 mm Crushed Type B and HL 4 stone. Although there are no data for the section of the deposit in Logan Township, it is possible that it contains material similar to that contained in the pits in McKillop Township. Testing is required to determine the quality of the material in Resource Area 4.

Resource Area 4 contains 65 acres (26 ha) available for extraction. Assuming a deposit thickness of 15 feet (5 m), the deposit contains approximately 2 million tons (2 million tonnes) of sand and gravel. Selected Resource Area 4 is accessible from various county and township roads.

Resource Areas Of Secondary Significance

Eight deposits of various origins have been selected at the secondary level of significance in Logan Township. The information available on several of these deposits is limited. Those pits that were opened in the deposits are abandoned and generally too overgrown to provide information on deposit characteristics. However, some MTO information is available for these sources. The deposits have been selected on the basis of the general characteristics of their deposit types in addition to the supporting data.

Two areas selected at the secondary level include an ice-contact and an ice-contact-esker deposit which traverse the northeastern part of Logan Township. No information is available on these two deposits, but similar deposits have been utilized as aggregate sources in the township.

Two ice-contact deposits located in central Logan Township have also been selected at the secondary level. There is little data available on the deposits, however, test hole LG-TH-3 was drilled in the largest deposit during the field investigation. The test hole revealed 7 feet (2 m) of silt with trace amounts of coarse sand. Although the test hole uncovered mainly silt, the deposits are as-

sociated with the ice-contact-esker complex which forms Resource Areas 1, 2 and 3. Consequently, the deposits may contain ice-contact material similar to that exposed in the Selected Resource Areas.

In southern Logan Township, west and northwest of Mitchell, there are two gravel outwash deposits which are considered to be of secondary significance, one deposit crosses the Logan-Hibbert township boundary. Abandoned pit nos. 20, 21 and 24 are located in these deposits. According to MTO records, pit no. 21 contained mainly sand suitable for only select subgrade uses (Deike 1982). Pit no. 20 had a face height of 10 to 15 feet (3 to 5 m) and contained 30 to 75% gravel. The pit is rated as being able to produce granular base course and 16 mm Crushed Type B (Deike 1982).

In the central part of the report area, three esker segments, two of which cross the Logan-Hibbert township boundary, are also at the secondary level of significance. In Logan Township, two overgrown pits are located in one of these deposits. MTO data for pit no. 22 indicate that it contained some coarse aggregate at one time, but now is considered to contain mainly sand (Deike 1982). Pit no. 23 had a face height of 15 feet (5m) and contained 20% gravel. The pit is described as containing crushable gravel in sections and as being able to produce granular base course and 16 mm Crushed Type B (Deike 1982). Sand control would be required for crushing. Discussions with the pit owner during field investigation revealed that concrete drainage tiles and concrete blocks were once produced using the aggregate from the pit. These deposits are expected to contain similar materials and have a comparable resource potential as described for the esker segments in the Hibbert Township, Resource Areas of Secondary Significance section of this report.

HIBBERT TOWNSHIP

Selected Sand And Gravel Resource Area 5

A large ice-contact deposit situated west of Dublin in Hibbert Township constitutes Selected Sand and Gravel Resource Area 5. The deposit was formed during the melting of the Lake Huron ice lobe. Selected Resource Area 5 contains 680 acres (275 ha), exclusive of licenced properties.

Two licenced and three unlicenced pits have been opened within the area. At the time of field investigation, licenced pit no. 6 contained well-stratified, coarse cobbly gravel with a clean medium to coarse sand matrix. Pit faces ranged in height from 20 to 25 feet (6 to 8 m) and contained approximately 40 to 70% gravel. A sample of the material from pit no. 6 contained 55% gravel, 44% sand and 1% fines (Figure 5a). The sample was crushable because 28% of the material was larger than 26.5 mm in size. The material in licenced pit no. 7 tended to be finer, and the pit contained no appreciable over-size. Faces in pit no. 7 ranged in height from 16 to 20 feet (5 to 6 m) and contained approximately 35 to 70% gravel.

Samples taken from the pit contained between 38 and 60% gravel (Figure 5a). MTO reports that the aggregate extracted from pit nos. 6, 7 and 28 has generally been acceptable for granular base course, 16 mm crushed stone and HL No. 4 and 8 stone. Sand control and selection would be necessary in sections of the pits for crushing operations, and blending would be required for the production of hot-laid sand. Generally, the material in pit nos. 6 and 7 was petrographically suitable for use in most aggregate products. Magnesium Sulphate Soundness and absorption tests supported this result (Table 9).

Selected Resource Area 5 contains approximately 550 acres (222 ha) available for extraction. Assuming an average deposit thickness of 20 feet (6 m), the area contains 28 million tons (25 million tonnes) of sand and gravel. The deposit is accessible by various township roads and is within close proximity to a line of the Canadian National Railways.

Selected Sand And Gravel Resource Area 6

Selected Sand and Gravel Resource Area 6 consists of two prominent ice-contact-kame deposits, designated as Areas 6a and 6b. These two hummocky deposits form the Staffa kame complex, which is located near Staffa in central Hibbert Township. The Resource Area contains large possible resources of sand and gravel and has been the site of large-scale extractive activity in the past. Four licenced and 7 unlicenced pits have been developed in the Resource Area. Faces in the pits ranged in height from 3 to 40 feet (1 to 12 m) and contained extremely variable gravel contents. Pit faces exhibited the variability that is characteristic of ice-contact deposits. Material exposed in the pit faces ranged from pockets of fine sand to cobbly gravel with abundant oversize material. Many of the pits were capped by a thick overburden of silty sand that must be removed prior to aggregate extraction. MTO has tested the aggregate in pit nos. 10 and 48 and report that the material extracted from these pits is generally acceptable for such uses as granular base course, 16 mm crushed stone and HL No. 4 and 8 stone. Because of the variability of the aggregate, selective extraction procedures may be necessary. Oversized clasts should be removed or crushed in a primary crusher. In sections of the pits, sand control would be necessary for crushing operations, and blending would be required for the production of asphalt sand. During field investigation, gravel was being extracted and crushed in portable crushing equipment in licenced pit no. 9. Samples taken from pit nos. 9, 10, 11 and 12 contained between 25 and 90% gravel and the gravel generally appeared to be suitable for crushing (Figures 6a to 8a).

Resource Area 6 occupies 540 acres (218 ha). Cultural constraints and previous extraction reduce the area currently available to 400 acres (162 ha). Assuming an average deposit thickness of 30 feet (9 m), the available sand and gravel resources are estimated to be 30 million tons (27 million tonnes). The resource area is readily accessible by County roads 10 and 16.

Resource Areas Of Secondary Significance

In Hibbert Township, several deposits of various origins have been selected at the secondary level of significance. Many of these deposits are limited in depth, however, they add significantly to the resource base of the township and should be considered an important part of the total aggregate supply.

In northern Hibbert Township there is a gravel outwash deposit considered to be of secondary significance. This deposit continues into southern Logan Township and has been discussed in the Logan Township, Resource Areas of Secondary Significance section.

Two eskers segments which cross the township boundaries in the central part of the report area, and one esker deposit located immediately northeast of Cromarty in Hibbert Township have also been selected at the secondary level of significance. Licenced pit no. 13 and abandoned pits nos. 22, 23, 37 to 45 and 57 have been developed within these deposits. Pits nos. 22 and 23 are located in Logan Township and were previously discussed (see Logan Township, Resource Areas of Secondary Significance). Faces in the other pits ranged in height from 3 to 15 feet (1 to 5 m) and exposed fine to coarse gravel and medium to coarse sand. Many of the pits were depleted of crushable material and, in some cases, were water filled. A sample of the material from pit no. 13 contained 57% gravel, 41% sand and 2% fines (Figure 8a). The sample was crushable because 24% of the material was larger than 26.5 mm in size. MTO has tested the aggregate in pit nos. 38 and 42 and reports that it is of high quality and suitable for such uses as granular base course, 16 mm crushed stone and HL No. 4 stone, with appropriate processing. Blending would be required for the production of hot-laid sand.

Several ice-contact-kame deposits located in the southern part of Hibbert Township have been selected as secondary areas. The deposits lack continuity and the material they contain can be extremely variable in grain size. Testing is required to delineate areas which may contain aggregate suitable for high-specification uses. Licenced pit nos. 15 and 16 and abandoned pit nos. 54, 59 and 63 are located in the deposits. The 10- to 25-foot (3 to 8 m) faces in licenced pit no. 15 have been cut into a high ice-contact hummock, consisting of material ranging in size from silty sand to coarse, cobbly gravel. Samples of the material taken from the pit contained between 29 and 63% gravel and two of the three samples appeared to be suitable for crushing (Figure 9a). The pit has been rated by MTO as being able to produce GBC A, B and C, 16 mm crushed stone and HL No. 4 and 8 stone. Sand control measures would be necessary for crushing operations in some sections of the pit. Pit workability problems include the presence of silt seams which should be avoided during extractive activity. Licenced pit no. 16 has been opened in an ice-contact deposit located south of licenced pit no. 15. Surface reserves within licenced pit no. 16 were nearing depletion and the 10- to 15-foot (3 to 5 m) faces in the pit generally exposed sandy aggregate with a few fine gravel lenses.

Samples of the material from the pit contained less than 20% gravel (Figure 10a). This material is likely to be best suited for pit-run use, as gravel in the crushable size range is lacking. Faces in pit nos. 54, 59 and 63 ranged in height from 5 to 15 feet (1.5 to 5 m) and exposed variable gravel contents. Fine to coarse angular gravel with medium to coarse sand was generally exposed in the pit faces. In general, the aggregate within these deposits is suitable for the production of a variety of aggregate products for local requirements.

Two more glaciofluvial outwash gravel deposits have been selected at the secondary level of significance. The outwash fan deposit (Karrow 1977) located northeast of Staffa contains licenced pit no. 8 and abandoned pit no. 46. Pit faces exposed up to 12 feet (4 m) of predominantly sand with some coarse gravel. Surface reserves in both pits are largely depleted. Data from MTO indicates that in the past, GBC A, B and C, 16 mm crushed stone and HL No. 4 and 8 stone have been produced from the pits, with appropriate processing. The sand is generally coarse, and blending is required for the production of asphalt sand. Pit no. 60 has been opened in a smaller outwash deposit located southwest of Cromarty. Fine to medium gravel and medium to coarse sand was observed within the 5- to 10-foot (1.5 to 3 m) pit face. This material was sampled and found to contain 60% gravel, 35% sand and 5% fines (Figure 11a). However, further testing will be required to establish the full resource potential.

BEDROCK GEOLOGY

The surficial deposits in Logan and Hibbert townships overlie the Amherstburg, Lucas and Dundee formations of Devonian age. The Lucas and Amherstburg formations form the Detroit River Group. The reader is referred to Uyeno et al. (1982) for a discussion of the nomenclatural history of these formations.

Most of Logan Township, and the northeast corner of Hibbert Township, is underlain by bedrock of the Detroit River Group. The lowermost unit in the group is the Amherstburg Formation, which underlies the northeast corner of Logan Township. In Logan Township, the Amherstburg Formation consists of dark brown, cherty, bituminous dolostone (Uyeno et al. 1982). Only minor amounts of the Amherstburg Formation are exposed in quarries in southern Ontario and there is very little available information on its suitability as a source of crushed aggregate. Testing is required to establish the quality of the Amherstburg Formation for these purposes. The Amherstburg Formation is covered by greater than 50 feet (15 m) of drift in the township. An oil and gas well (LG-TH-4) drilled through the Lucas and Amherstburg formations showed 143 feet (44 m) of Amherstburg Formation below the Lucas Formation.

The Lucas Formation extends from northwestern Logan Township to northeastern Hibbert Township and is the major bedrock unit. In Ontario, the formation can be subdivided into undifferentiated Lucas Formation

and the Anderdon Member of the Lucas Formation (Uyeno et al. 1982). The Anderdon Member is a very high purity limestone which is quarried near Ingersoll and Amherstburg for use in the production of flux stone, lime and Portland cement. Undifferentiated Lucas Formation consists of thin- to medium-bedded, light brown to grey-brown, finely crystalline, poorly fossiliferous dolostone with minor chert, dark bituminous laminations, and local mottling (Uyeno et al. 1982). Being a dolostone, undifferentiated Lucas Formation is not used in lime and cement production. It is quarried at Amherstburg for crushed stone, and is a borderline to acceptable source of granular base course products and subbase course products (Derry Michener Booth and Wahl and Ontario Geological Survey 1989). Problems with excessive fines, high absorption and soundness losses have been experienced with some of this material (Koniuszy and Katona 1981). Testing would be required to establish the quality of the Lucas Formation in Logan and Hibbert townships.

There are only a few small areas of Lucas Formation with less than 25 feet (8 m) of drift cover. The remaining drift varies from 25 feet (8 m) to well over 100 feet (30 m) thick. An oil and gas well (LG-TH-4) drilled into the Lucas strata revealed 192 feet (58 m) of the formation.

The Dundee Formation underlies the southwestern part of Logan Township and most of Hibbert Township. The formation is a medium- to thick-bedded, dark brown, fossiliferous, micritic limestone (Uyeno et al. 1982). It contains bituminous laminations, shaly partings, chert nodules and lenses of coarse-grained limestone. The formation is quarried for use in the production of Portland cement in St. Marys (Derry Michener Booth and Wahl and Ontario Geological Survey 1989). In Amherstburg, the formation is not of sufficient quality for this use, however, it is quarried for crushed stone. The quarries produce primarily granular base course products (Koniuszy and Katona 1981). Generally, the Dundee Formation limestone that is quarried as crushed stone in southern Ontario tends to be soft, has Los Angeles Abrasion test results of 22 to 32% loss, is sound, and has absorption test values as high as 4% (Hewitt 1960). One building stone quarry has been opened in the Dundee Formation near Cromarty, quarry no. 1. The inactive quarry is largely overgrown. A 3- to 6-foot (1 to 2 m) face exposes flat-lying and irregularly bedded, grey fossiliferous limestone. The suitability of the bedrock for use in the production of crushed stone products or Portland cement can only be established by testing.

Devonian strata in this part of southwestern Ontario have a gentle regional dip westward towards the centre of deposition in the Michigan basin (Karrow 1977; Uyeno et al. 1982). Drift thickness in the report area varies from over 200 feet (61 m) southwest of Dublin, to zero at the quarry site. Large areas of shallow drift [less than 50 feet (15 m)] occur near Cromarty and Staffa. Sinkhole development is pronounced within this area. No areas of bedrock have been selected for possible resource protection. Oil and gas wells drilled into

the Dundee Formation (LG-TH-6, LG-TH-7, LG-TH-8) show 36 to 52 feet (11 to 16 m) of the limestone overlying the Detroit River Group.

SUMMARY

The sand and gravel resources of Logan and Hibbert townships were deposited during the "Great Ice Age". Four ice-contact-esker deposits located in Logan Township, and three large ice-contact-kame deposits located in Hibbert Township, have been selected for possible resource protection at the primary level. Logan Township contains limited possible resources of sand and gravel which will likely be insufficient for local needs in the near future, and will require augmentation from outside sources. Care should be taken to ensure the proper utilization of the remaining resources. In contrast, the selected deposits in Hibbert Township contain significant resources of sand and gravel suitable for use in a variety of road and general construction products. These deposits should be able to meet local aggregate demands for a considerable period of time. In addition to the Primary resources, several esker, ice-contact, ice-contact-kame, ice-contact-esker and outwash deposits located in both townships have been designated as resources of secondary significance.

Three bedrock formations of Devonian age underlie Logan and Hibbert townships. All of the formations may be suitable for use as crushed stone, however, bedrock suitability can only be established by testing. Drift thickness is generally too great in the majority of the report area to permit the economic extraction of the rock for aggregate purposes. For these reasons no bedrock resource areas have been selected.

Enquiries regarding the Aggregate Resources Inventory of Logan and Hibbert townships should be directed to the Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Ontario Ministry of Northern Development and Mines, 7th Floor, 77 Grenville Street, Toronto, Ontario, M7A 1W4 [Tel. (416) 965-1663], or to the Resident Geologist, Southwestern District, Southern Ontario Region, Ontario Ministry of Northern Development and Mines, P.O. Box 5463, 659 Exeter Road, London, Ontario, N6A 4L6 [Tel. (519) 661-2773], or to the Aggregate Resource Geologist, Ontario Ministry of Natural Resources, Box 5463, 659 Exeter Road, London, Ontario, N6A 4L6 [Tel. (519) 661-2709], or to the Ontario Ministry of Natural Resources at the Wingham District Office, R.R. 5, Wingham, Ontario, N0G 2W0 [Tel. (519) 357-3131].

TABLE 1. TOTAL SAND AND GRAVEL RESOURCES, LOGAN AND HIBBERT TOWNSHIPS.

1	2	3	4	1	2	3	4
CLASS NO.	DEPOSIT TYPE (see Appendix C)	AREAL EXTENT Acres (Hectares)	ORIGINAL TONNAGE Millions of Tons (Tonnes)	CLASS NO.	DEPOSIT TYPE (see Appendix C)	AREAL EXTENT Acres (Hectares)	ORIGINAL TONNAGE Millions of Tons (Tonnes)
Logan Township					G-IC-K	25 (10)	1 (1)
1	S-IC-E	415 (168)	21 (19)		G-OW	2 (1)	< 1 (< 1)
2	G-E	50 (20)	2 (2)		S-IC-K	375 (152)	14 (13)
	G-OW	60 (24)	2 (2)	3	G-E	45 (18)	1 (1)
	S-IC	235 (95)	9 (8)		G-IC-K	65 (26)	1 (1)
	S-IC-E	305 (123)	12 (11)		G-OW	265 (107)	6 (5)
3	G-OW	64 (26)	1 (1)		S-IC-K	145 (59)	3 (3)
	S-E	22 (9)	< 1 (< 1)	4	G-OW	105 (42)	1 (1)
	S-IC-E	185 (75)	4 (4)		S-IC-K	15 (6)	< 1 (< 1)
		1340 (540)	51 (46)			2850 (1150)	134 (122)
Hibbert Township							
1	G-IC-K	1620 (660)	101 (92)				
2	G-E	175 (71)	6 (5)				
				TOTAL FOR STUDY AREA:		4200 (1700)	185 (168)

N.B. Minor variations in all tables are caused by rounding of data.

* Identified deposit areas within the Town of Mitchell are omitted on all tables.

TABLE 2. SAND AND GRAVEL PITS, LOGAN AND HIBBERT TOWNSHIPS.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREAS Acres (Hectares)	7 FACE HEIGHT Feet (Metres)	8 % GRAVEL
LICENCED PITS							
Logan Township							
1	S4-1 S4-87	Machan Construction Ltd.	Pt.31	15.16	105.0 (42.5)	10-15 (3-5)	5-50 partially overgrown and water filled
2	S4-79	Logan Township	Pt.30	15	6.2 (2.5)	5-15 (1.5-5)	20-50 partially slumped and water filled
3	S4-80	M. Brown	3014		100.0 (40.5)	5-15 (1.5-5)	15-50 partially overgrown
4	S4-82	Machan Construction Ltd.	Pt.30	13	61.8 (25.0)	5-15 (1.5-5)	0-75 partially water filled
5	S4-31	Sherbarth	30	13	18.5 (7.5)	20-25 (6-8)	60 partially overgrown
					291.5 (118.0)		
Hibbert Township							
6	S04-069	Vandervliet	Pt. 22.23	3	127.2 (51.5)	20-25 (6-8)	40-70
7	S04-065	Van Loon	Pt.21	3	54.6 (22.1)	16-20 (5-6)	35-70
8	S08-051	Yundt Bros. Const. Ltd.	Pt.10	6	32.6 (13.2)	5-10 (1.5-3)	30-55 variable, overgrown
9	S08-097	DRD Farms Ltd.	12,13	7	204.1 (82.6)	16-20 (5-6)	40-70
10	S08-21 S08-106	Parsons	Pt.15	9	93.67 (37.91)	25-40 (8-12)	25-90 variable
11	-	Gardiner	Pt.16	10	10.6 (4.3)	13-26 (4-8)	30-50
12	S08-087	Tinney-Beer	Pt.15	10	14.6 (5.9)	10-40 (3-12)	variable
13	-	Ruston	Pt.13	10	13.0 (5.3)	5-8 (1.5-2)	40-60
14	-	Riley	Pt.22	12	25.29 (10.20)	unopened	
15	S08-040	McDowell	Pt.30	13	89.9 (36.4)	10-25 (3-8)	30-65 variable
16	S08-111	Riley	Pt.30	14	8.35 (3.38)	10-15 (3-5)	10-20
					673.91 (272.73)		
Total Licenced Area in Logan and Hibbert Townships:					965.41 (390.70)		

TABLE 2. SAND AND GRAVEL PITS, LOGAN AND HIBBERT TOWNSHIPS.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREAS Acres (Hectares)	7 FACE HEIGHT Feet (Metres)	8 % GRAVEL
UNLICENCED PITS*							
Logan Township							
17	S4-122	M. Rock	30	15	-	8-15 (2-5)	60-70 rehabilitated
18	S4-88	Bauer	28	11	-	10-25 (3-8)	5-60 rehabilitated, water filled
19	-	unknown	9,10	10	-	8 (2)	overgrown
20	S8-101	Reaney	19	2	-	10-15 (3-5)	30-75
21	S8-105	Eickmeyer	20	2	-	-	-
22	S8-69	Barker	25	1	-	8-10 (2-3)	sand overgrown
23	S8-45	Robinson	24	1	-	15 (5)	20 partially overgrown
24	-	unknown	25	1	-	10 (3)	overgrown
Hibbert Township							
25	-	unknown	28	2	-	5-8 (1.5-2)	variable, partially overgrown
26	-	unknown	27	2	-	3-8 (1-2)	variable, overgrown
27	-	unknown	26	2	-	10-20 (3-6)	variable, partially overgrown, water filled
28	S04-072	Poland	23	2	-	15-30 (5-9)	30-40 partially overgrown
29	-	unknown	21	2	-	5-10 (1.5-3)	overgrown
30	-	unknown	23	3	-	10-20 (3-6)	overgrown
31	-	unknown	18	3	-	5-8 (1.5-2)	clay pit, overgrown
32	-	unknown	16	3	-	3-5 (1-1.5)	clay pit, overgrown
33	-	unknown	18	3	-	10-15 (3-5)	overgrown
34	-	unknown	18	4	-	5-10 (1.5-3)	< 20
35	-	unknown	23	6	-	10 (3)	variable, overgrown
36	-	unknown	22	5	-	15-20 (5-6)	variable, overgrown

TABLE 2. SAND AND GRAVEL PITS, LOGAN AND HIBBERT TOWNSHIPS.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREAS Acres (Hectares)	7 FACE HEIGHT Feet (Metres)	8 % GRAVEL
37	S08-098	Luadze	9	1	-	5-10 (1.5-3)	overgrown, water filled
38	-	unknown	8	1	-	5-10 (1.5-3)	overgrown, water filled
39	S08-071	Schoonderwoerd	1	1	-	12 (4)	30-50 overgrown, water filled
40	S08-095	Schoonderwoerd	2	1	-	3-5 (1-1.5)	overgrown
41	-	unknown	2	1	-	3-8 (1-2)	30-40
42	-	unknown	3	1	-	5-10 (1.5-3)	30-40 overgrown
43	S08-056	Kumm	4	1	-	5-15 (1.5-5)	30-50 variable, overgrown
44	-	unknown	5	2	-	5-15 (1.5-5)	30-50 overgrown, water filled
45	S08-077	Gardiner	5	2	-	5-10 (1.5-3)	30-50 variable, overgrown
46	S08-096	Manon	11	6	-	10-12 (3-4)	30-60 overgrown
47	S08-108	Smale	24	8	-	10-15 (3-5)	10-20 partially overgrown
48	S08-052	Butson (Sandy Construction)	14	8	-	10-35 (3-11)	30-70 partially overgrown
49	-	unknown	14	8	-	10-20 (3-6)	variable, overgrown
50	-	unknown	14	8	-	10-15 (3-5)	variable, partially overgrown
51	-	unknown	11	8	-	3 (1)	overgrown
52	S08-003	Norris	12	8	-	5-10 (1.5-3)	overgrown
53	-	unknown	12	8	-	3-5 (1-1.5)	overgrown
54	-	unknown	6	8	-	10-15 (3-5)	30-40 overgrown
55	S08-107	Drake	16	9	-	5-10 (1.5-3)	variable, overgrown
56	-	unknown	16	9	-	5-10 (1.5-3)	overgrown, partially rehabilitated
57	S08-053	Templeton	12	9	-	5-10 (1.5-3)	overgrown

TABLE 2. SAND AND GRAVEL PITS, LOGAN AND HIBBERT TOWNSHIPS.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREAS Acres (Hectares)	7 FACE HEIGHT Feet (Metres)	8 % GRAVEL
58	-	unknown	Pt. 24,25	12	-	5-10 (1.5-3)	30-40 variable, overgrown
59	-	unknown	24	12	-	5-10 (1.5-3)	30-40 variable, overgrown, water filled
60	-	unknown	20	13	-	5-10 (1.5-3)	30-60 overgrown
61	S08-091	Meikle	13	14	-	5 (1.5)	overgrown
62	S08-028	Harburn	10	14	-	5 (1.5)	30-40 partially overgrown
63	S08-015	Christie	4	13	-	5-15 (1.5-5)	10-40 variable, overgrown

* Abandoned pits or wayside pits operating on demand under authority of a permit.

TABLE 3. SELECTED SAND AND GRAVEL RESOURCE AREAS, LOGAN AND HIBBERT TOWNSHIPS.

1 DEPOSIT NO.	2 UNLICENCED AREA Acres (Hectares)	3 CULTURAL SETBACKS Acres (Hectares)	4 EXTRACTED AREA Acres (Hectares)	5 AVAILABLE AREA Acres (Hectares)	6 ESTIMATED DEPOSIT THICKNESS Feet (Metres)	7 AVAILABLE AGGREGATE Millions of Tons (Tonnes)
Logan Township						
1	120 (49)	57 (23)	3 (1)	60 (24)	20 (6)	3 (3)
2	100 (40)	17 (7)	3 (1)	80 (32)	20 (6)	4 (4)
3	230 (93)	21 (8)	4 (2)	205 (83)	15 (5)	8 (7)
4	77 (31)	12 (5)	0 (0)	65 (26)	15 (5)	2 (2)
	<u>530</u> (214)	<u>107</u> (43)	<u>10</u> (4)	<u>410</u> (166)		<u>17</u> (15)
Hibbert Township						
5	680 (275)	115 (46)	15 (6)	550 (222)	20 (6)	28 (25)
6a	275 (111)	35 (14)	20 (8)	220 (89)	30 (9)	16 (14)
6b	265 (107)	70 (28)	15 (6)	180 (73)	30 (9)	14 (13)
	<u>540</u> (218)	<u>105</u> (42)	<u>35</u> (14)	<u>400</u> (162)		<u>30</u> (27)
	<u>1220</u> (495)	<u>220</u> (89)	<u>50</u> (20)	<u>950</u> (385)		<u>58</u> (53)
TOTAL FOR STUDY AREA:	<u>1750</u> (710)	<u>325</u> (132)	<u>60</u> (24)	<u>1360</u> (550)		<u>75</u> (68)

TABLE 4. TOTAL IDENTIFIED BEDROCK RESOURCES, LOGAN AND HIBBERT TOWNSHIPS.

1 DRIFT THICKNESS Feet (Metres)	2 FORMATION	3 ESTIMATED DEPOSIT THICKNESS Feet (Metres)	4 AREAL EXTENT Acres (Hectares)	5 ORIGINAL TONNAGE Millions of Tons (Tonnes)
Logan Township				
25-50 (8-15)	Dundee Formation	40 (12)	40 (16)	6 (5)
3-25 (1-8)	Lucas Formation	60 (18)	3 (1)	1 (1)
25-50 (8-15)	Lucas Formation	60 (18)	7000 (2850)	1500 (1360)
			7000 (2850)	1500 (1360)
Hibbert Township				
0-3 (0-1)	Dundee Formation	60 (18)	17 (7)	4 (4)
3-25 (1-8)	Dundee Formation	60 (18)	275 (111)	59 (54)
25-50 (8-15)	Dundee Formation	60 (18)	5800 (2350)	1250 (1130)
			6100 (2470)	1310 (1190)
TOTAL FOR STUDY AREA:			13 100 (5300)	2800 (2550)

TABLE 5. QUARRIES, LOGAN AND HIBBERT TOWNSHIPS.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREA Acres (Hectares)	7 FACE HEIGHT Feet (Metres)
LICENCED QUARRIES						
Logan Township						
			- NONE -			
Hibbert Township						
			- NONE -			
UNLICENCED QUARRIES*						
Logan Township						
			- NONE -			
Hibbert Township						
1	-	unknown	19	11	-	3-6 (1-2)

* Abandoned quarries or wayside quarries operating on demand under authority of a permit.

TABLE 6. SELECTED BEDROCK RESOURCE AREAS, LOGAN AND HIBBERT TOWNSHIPS.

1 DEPOSIT NO.	2 DEPTH OF OVERBURDEN Feet (Metres)	3 UNLICENCED AREA Acres (Hectares)	4 CULTURAL SETBACKS Acres (Hectares)	5 EXTRACTED AREA Acres (Hectares)	6 AVAILABLE AREA Acres (Hectares)	7 ESTIMATED WORKABLE THICKNESS Feet (Metres)	8 AVAILABLE RESOURCES Millions of Tons (Tonnes)
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- NONE -

TABLE 7. SUMMARY OF TEST HOLE DATA, LOGAN AND HIBBERT TOWNSHIPS.

LOGAN TOWNSHIP		58-250 (18-76)	Lucas Formation, Detroit River Group
Test Hole Number: LG-TH-1		250-393 (76-120)	Amherstburg Formation, Detroit River Group
Location: Lot 31, Conc. 16, Logan Township		test hole continued to 1318 feet (402 m) where it was abandoned because it was a dry hole	
Elevation: Approximately 1175 feet (358 m) asl			
Date: October 28, 1982		Test Hole Number: LG-TH-5	
Depth feet (metres)	Description	Location: Lot 11, Conc. 11, Logan Township	
0-8 (0-2)	silty fine sand with some fine gravel; sample taken at 5 feet (1.5 m) for analysis	Elevation: Approximately 1182 feet (360 m) asl	
8-10 (2-3)	silt with very fine sand, some medium to coarse sand and a trace very fine gravel	Date: August 12, 1955	
	sample taken at 8 feet (2 m) for analysis; hole terminated at 10 feet (3 m) because machine could not penetrate further; no water encountered	Depth feet (metres)	Description
		0-50 (0-15)	drift
		50-340 (15-104)	Detroit River Group
Test Hole Number: LG-TH-2		test hole continued to 1350 feet (411 m) where it was abandoned because it was a dry hole	
Location: Lot 28, Conc. 10, Logan Township			
Elevation: Approximately 1150 feet (350 m) asl		Test Hole Number: LG-TH-6	
Date: October 28, 1982		Location: Lot 31, Conc. 3, Logan Township	
Depth feet (metres)	Description	Elevation: Approximately 1127 feet (344 m) asl	
0-11 (0-3)	coarse sand and fine gravel with fine to medium sand and some silt	Date: November 11, 1954	
	hole terminated at 11 feet (3 m) because machine could not penetrate further	Depth feet (metres)	Description
		0-70 (0-21)	drift
		70-122 (21-37)	Dundee Formation
Test Hole Number: LG-TH-3		122-561 (37-171)	Detroit River Group
Location: Lot 21, Conc. 7, Logan Township		test hole continued to 1718 feet (524 m) where it was abandoned because it was a dry hole	
Elevation: Approximately 1125 feet (343 m) asl			
Date: October 28, 1982		Test Hole Number: LG-TH-7	
Depth feet (metres)	Description	Location: Lot 29, Conc. 2, Logan Township	
0-7 (0-2)	silt with trace coarse sand	Elevation: Approximately 1129 feet (344 m) asl	
	hole terminated at 7 feet (2 m) because drill would not penetrate material below; no water encountered	Date: November 8, 1955	
Test Hole Number: LG-TH-4*		Depth feet (metres)	Description
Location: Lot 21, Conc. 16, Logan Township		0-110 (0-34)	drift
Elevation: Approximately 1175 feet (358 m) asl		110-159 (34-48)	Dundee Formation
Date: August 9, 1973		159-430 (48-131)	Detroit River Group
Depth feet (metres)	Description	test hole continued to 1474 feet (449 m) where it was abandoned because it was a dry hole	
0-58 (0-18)	drift		

TABLE 7. SUMMARY OF TEST HOLE DATA, LOGAN AND HIBBERT TOWNSHIPS.

Test Hole Number: LG-TH-8		Source: University of Waterloo BH 44-74, Ontario Division of Mines, Geoscience Report 148, 1977.	
Location: Lot 26, Conc. 3, Logan Township		Depth	Description
Elevation: Approximately 1132 feet (345 m) asl		feet (metres)	
Date: December 31, 1955		0-4 (0-1.3)	bluff soil and stony silt
Depth	Description	4-9 (1.3-2.7)	brown, clayey silt till. Sample 44-74A at 5 feet (1.5 m)
feet (metres)		9-12 (2.7-3.7)	grey, sandy silt till. Sample 44-74B at 11 feet (3.4 m)
0-93 (0-28)	drift	12-16 (3.7-4.9)	buff, hard, stony silt till
93-129 (28-39)	Dundee Formation	16-30.5 (4.9-9.3)	grey, stony sandy silt till. Sample 44-74C at 19 feet (5.8 m). Sample 44-74D at 26 feet (7.9 m)
129-428 (39-130)	Detroit River Group	30.5-32 (9.3-9.8)	dense, blocky, silt till. Sample 44-74E at 31 feet (9.5 m)
	test hole continued to 1442 feet (440 m) where it was abandoned because it was a dry hole	32-40 (9.8-12.2)	grey to buff, banded, stylolitic limestone
HIBBERT TOWNSHIP			
Test Hole Number: HI-TH-9			
Location: Lot 20, Concession 9, Hibbert Township			
Elevation: Approximately 1025 feet (312 m) asl			

* Data for test holes LG-TH-4 to LG-TH-8 was supplied by Petroleum Resources Laboratory, Ministry of Natural Resources, London. See Map 3 for locations.

TABLE 8. SUMMARY OF GEOPHYSICS DATA, LOGAN AND HIBBERT TOWNSHIPS.

- NONE -

TABLE 9. RESULTS OF AGGREGATE QUALITY TESTS, LOGAN AND HIBBERT TOWNSHIPS.

COARSE AGGREGATE						FINE AGGREGATE
Petrographic Number						
Pit No.	GBC & 16 mm Crushed	Hot Mix & Concrete	Magnesium Sulphate Soundness (% Loss)	Absorption (%)	Los Angeles Abrasion (% Loss)	Magnesium Sulphate Soundness (% Loss)
Logan Township						
Licenced Pit 1						
1b	163.3	208.2	11.9	1.77	-	59.6
1c	105.1	135.6	3.3	-	-	15.3
Licenced Pit 3						
3a	104.1	138.8	7.1	1.43	-	12.0
Licenced Pit 4						
4b	101.0	136.7	4.0	1.10	-	6.3
Hibbert Township						
Licenced Pit 6						
6	102.4	121.3	5.8	1.74	-	9.9
Licenced Pit 7						
7a	107.6	150.0	5.2	1.69	-	7.9
7b	100.0	114.8	3.8	-	-	11.5
Licenced Pit 9						
9a	103.8	128.4	6.0	1.67	-	15.6
9b	100.0	133.9	1.8	1.50	-	11.4
9c	100.0	108.3	2.1	1.33	-	11.6
Licenced Pit 10						
10a	102.0	128.8	-	1.90	-	16.7
10c	101.7	130.2	3.5	1.58	-	9.9
10d	107.7	123.1	5.3	1.54	-	6.7
Licenced Pit 11						
11a	139.0	162.2	6.8	1.78	-	10.9
11b	100.0	114.2	3.3	1.35	-	8.5
Licenced Pit 12						
12	100.0	116.0	-	-	-	11.0
Licenced Pit 13						
13	116.5	152.5	9.3	1.98	-	15.3
Licenced Pit 15						
15a	111.4	150.0	-	-	-	7.6
15b	116.4	137.6	6.4	1.86	-	10.2
15c	103.9	140.2	6.7	1.70	-	11.6
Licenced Pit 16						
16b	-	-	-	-	-	7.9

SOURCE: Wingham District Office, Ontario Ministry of Natural Resources

NOTE: The quality test data refers strictly to a specific sample. Because of the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

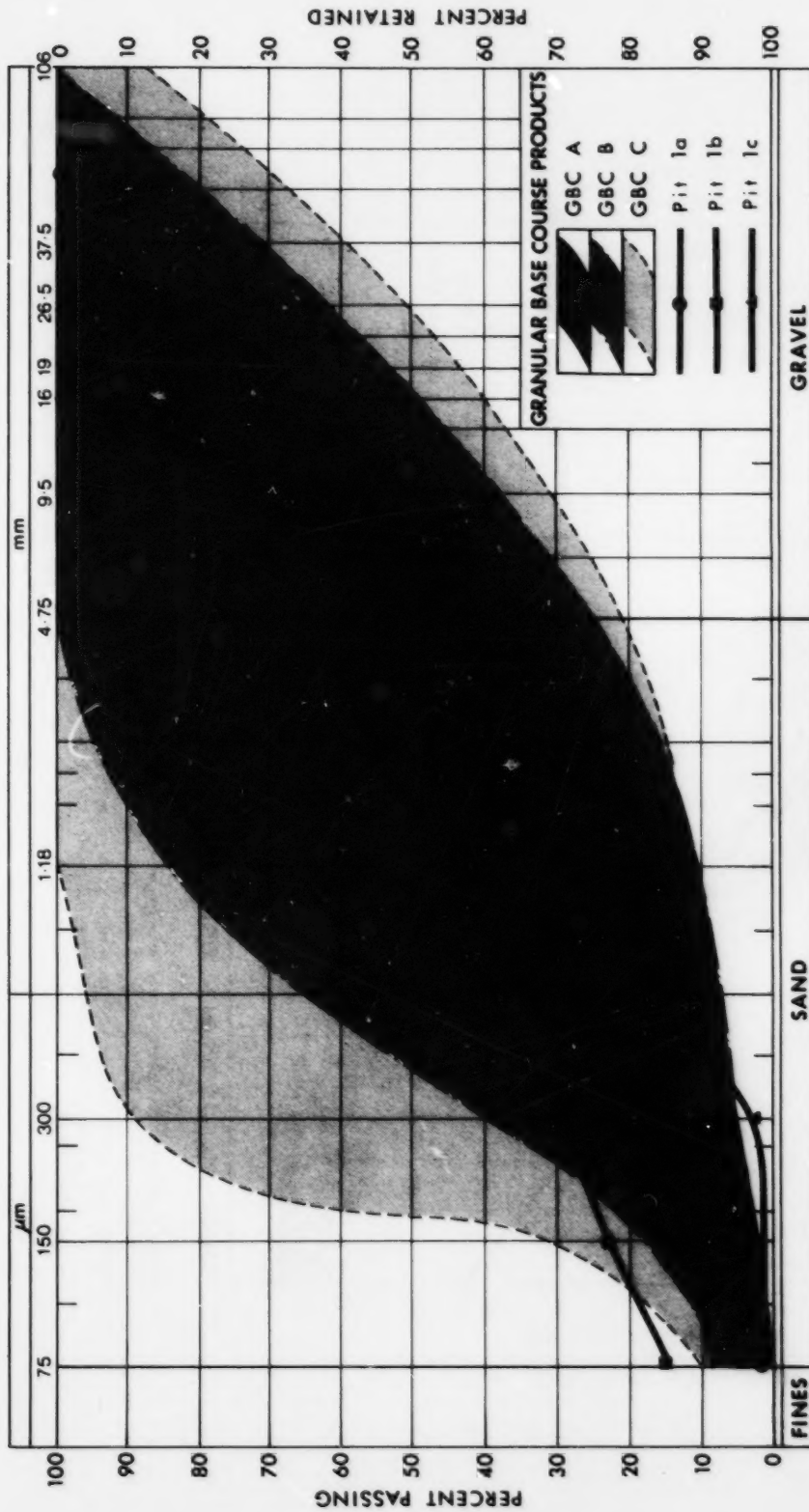


FIGURE 2a. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

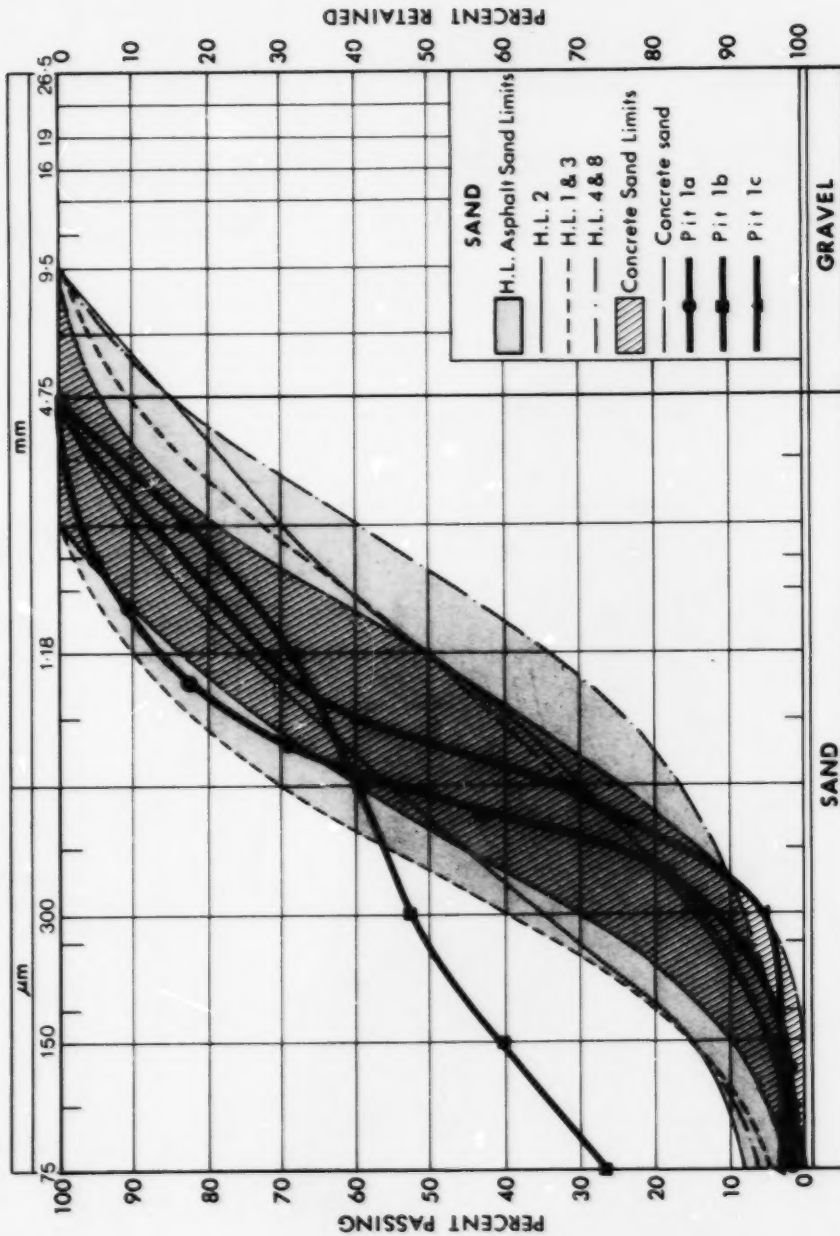
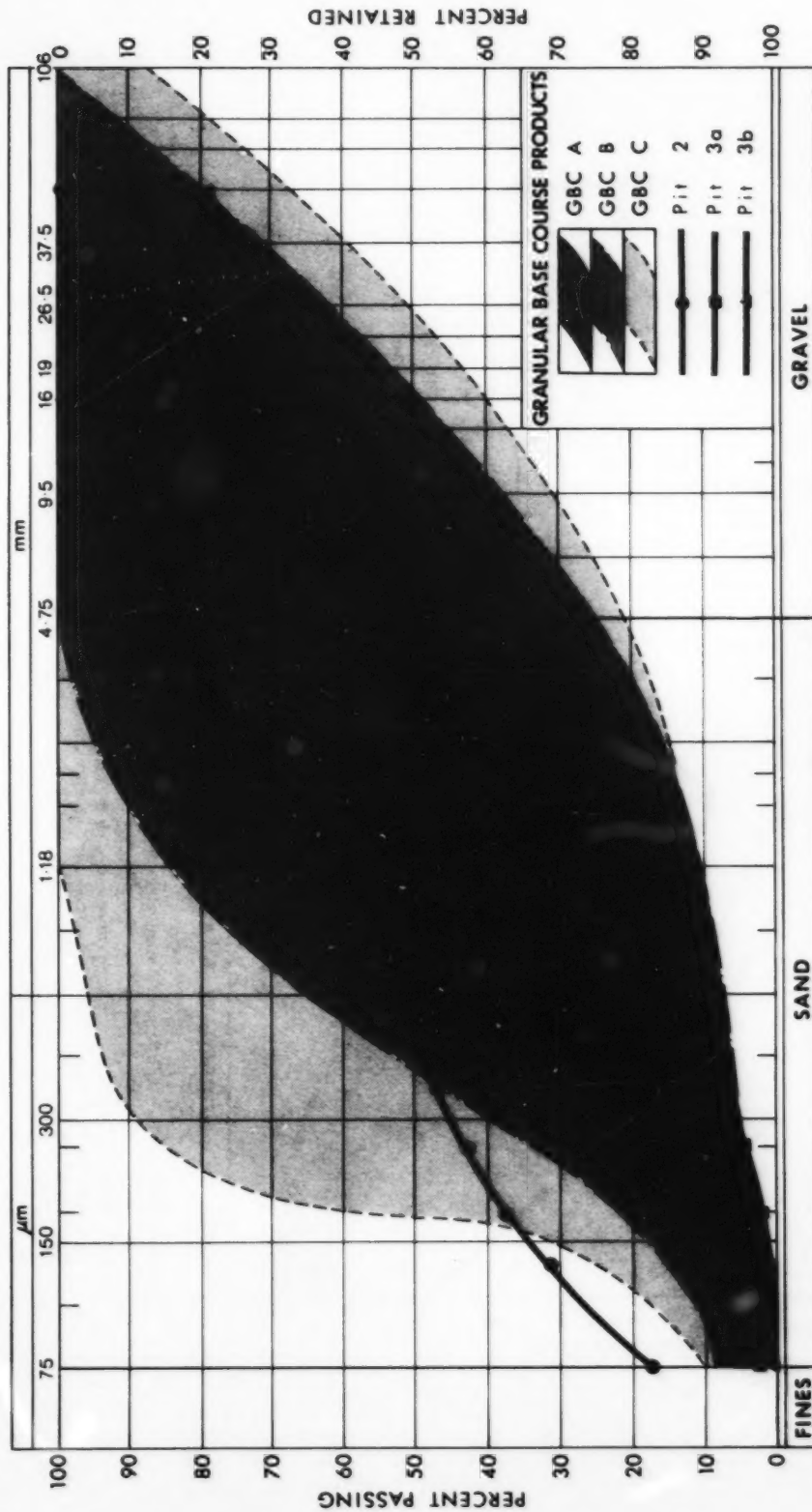


FIGURE 2b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.



Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

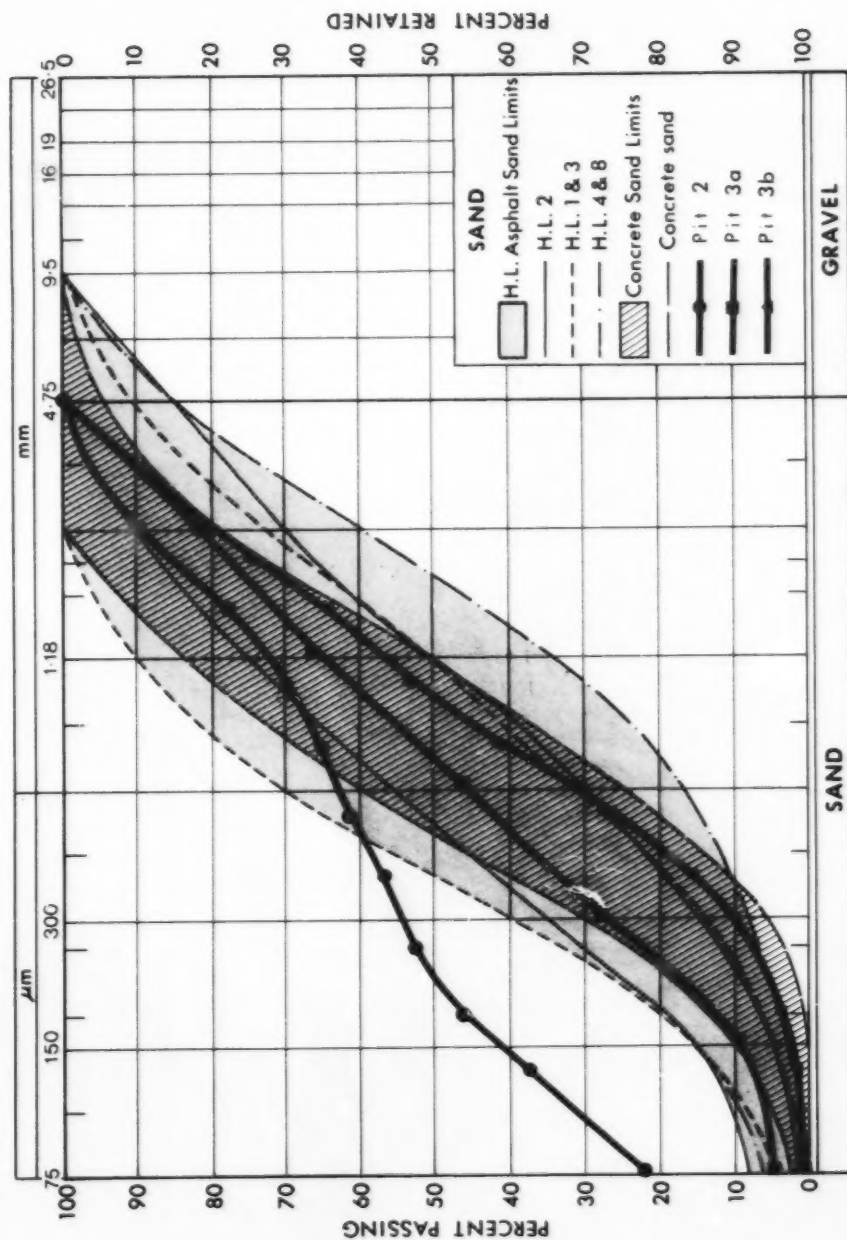


FIGURE 3b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

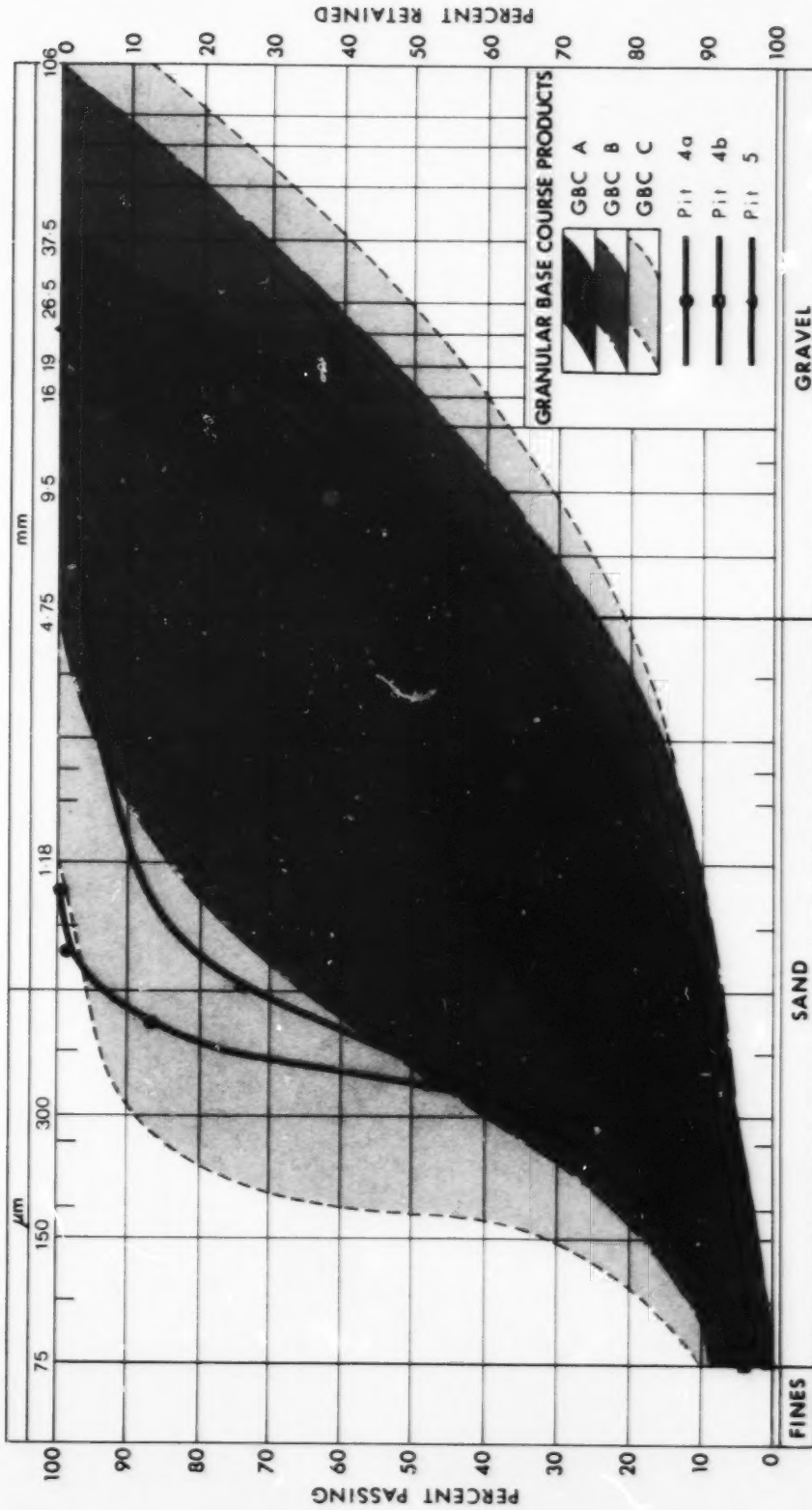


FIGURE 4a. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

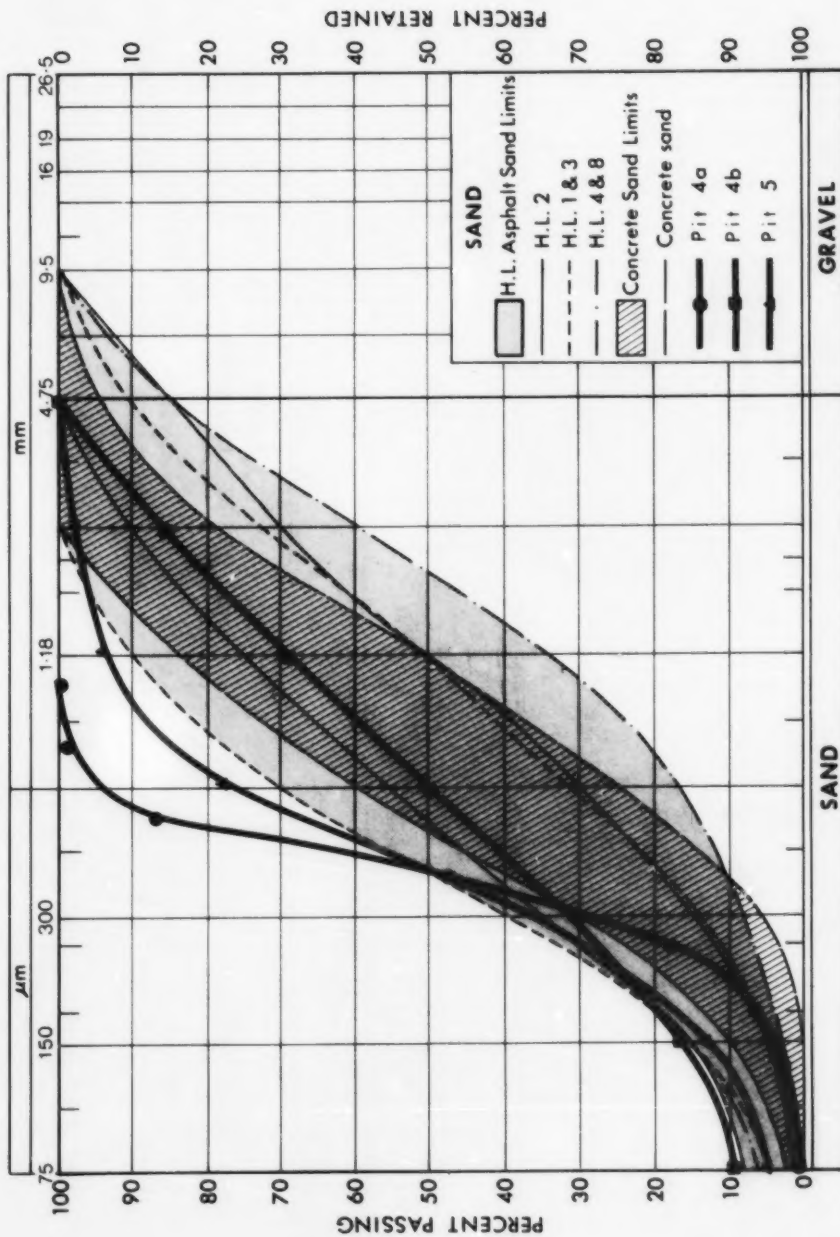


FIGURE 4b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

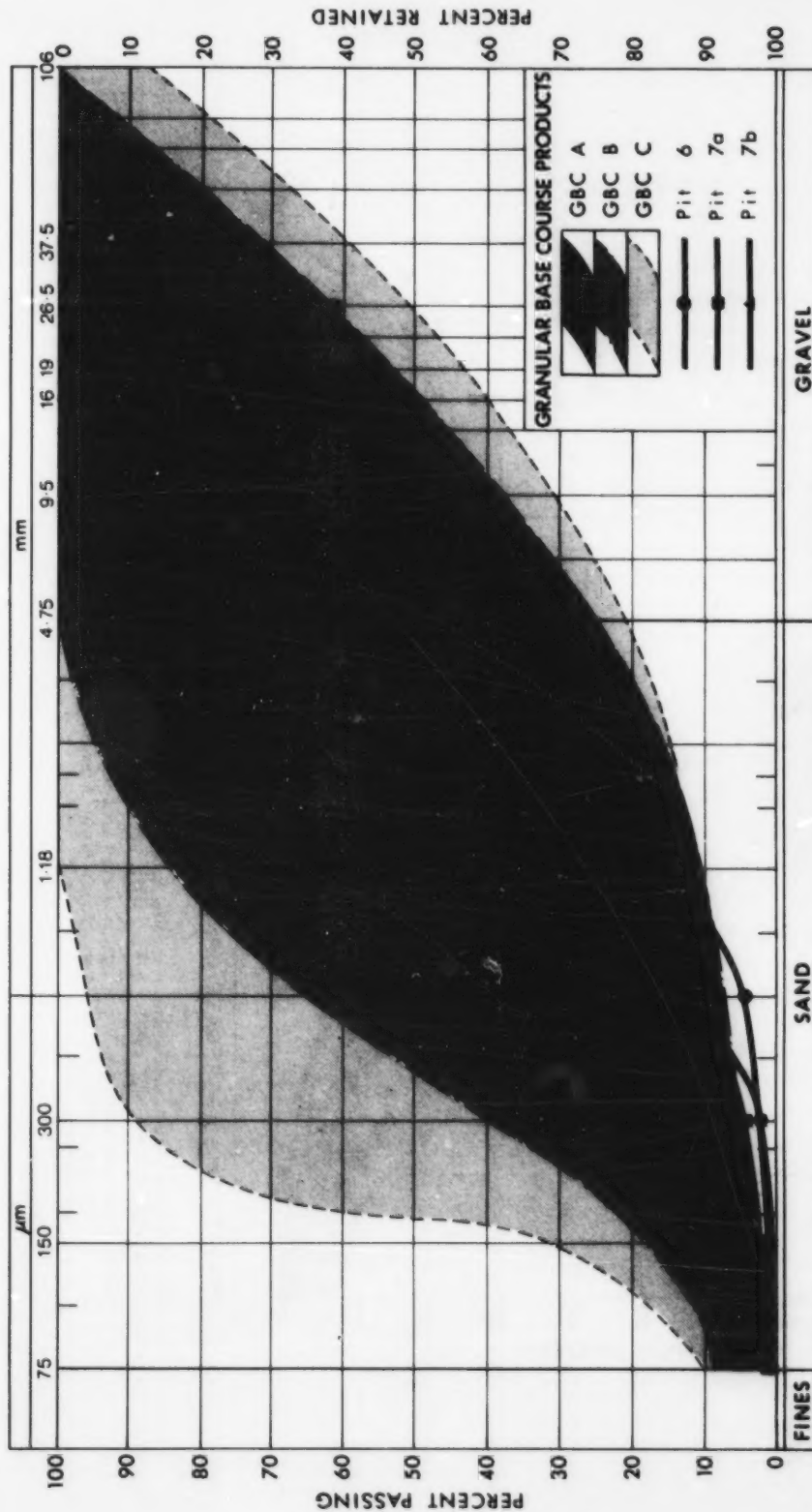


FIGURE 5a. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

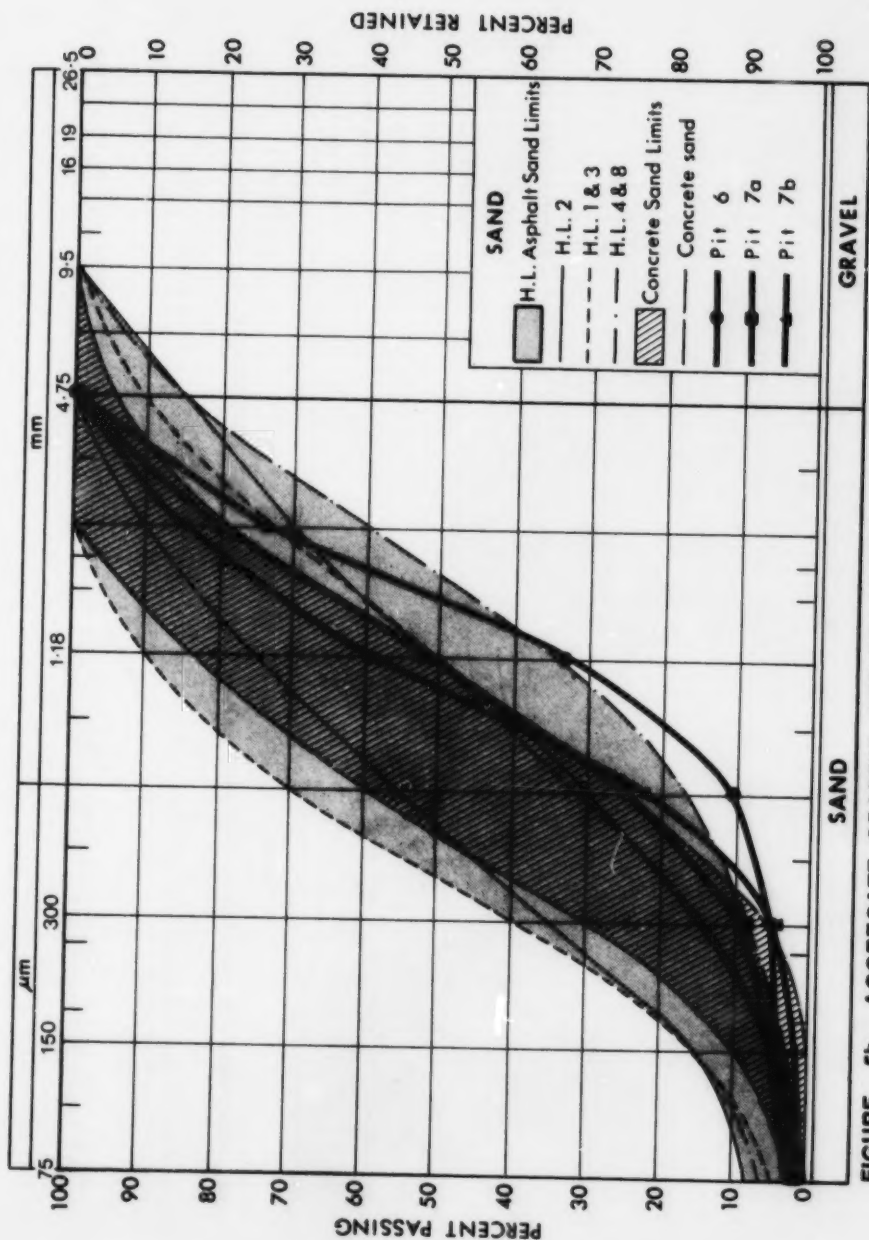
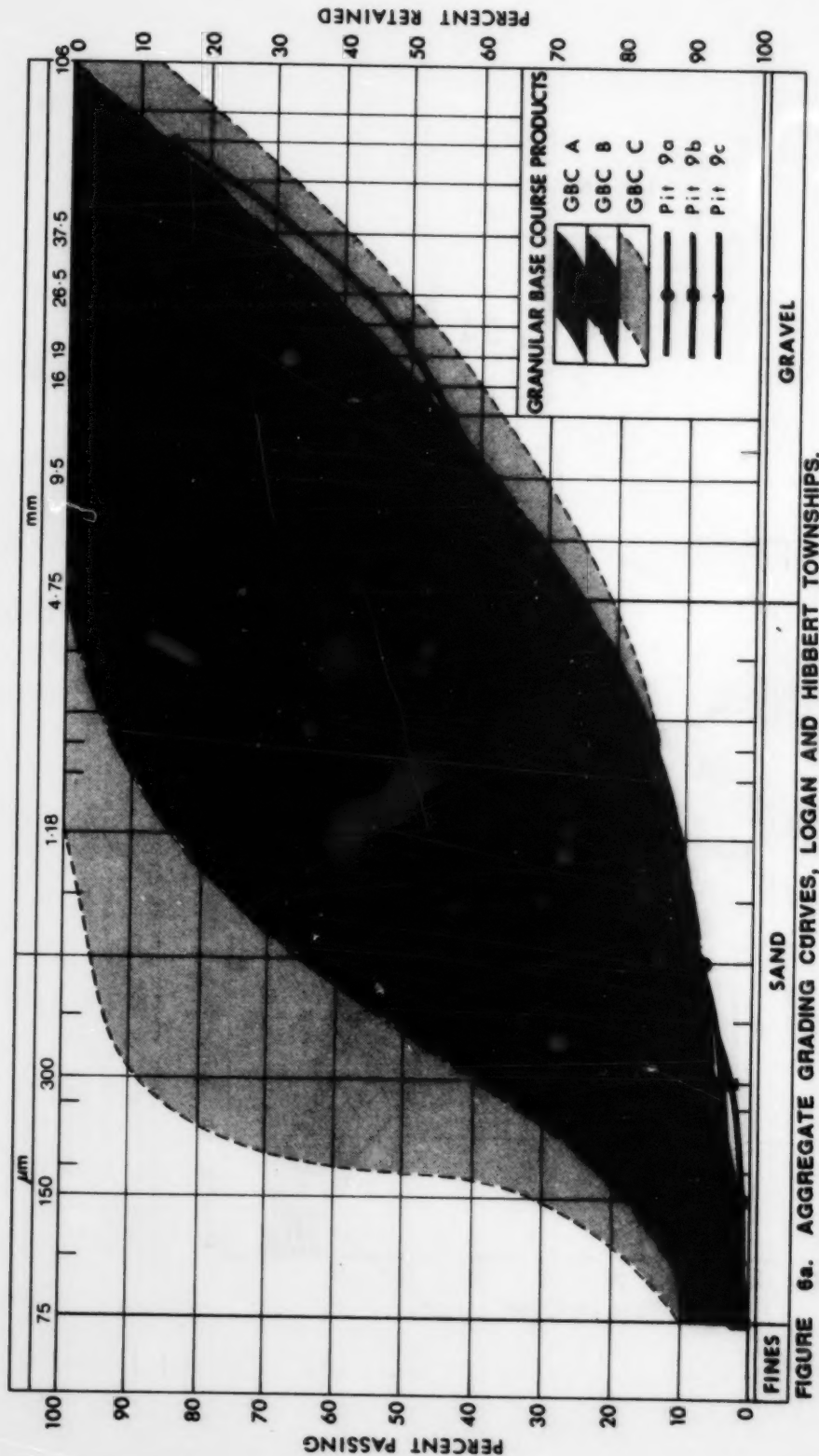


FIGURE 5b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.



Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

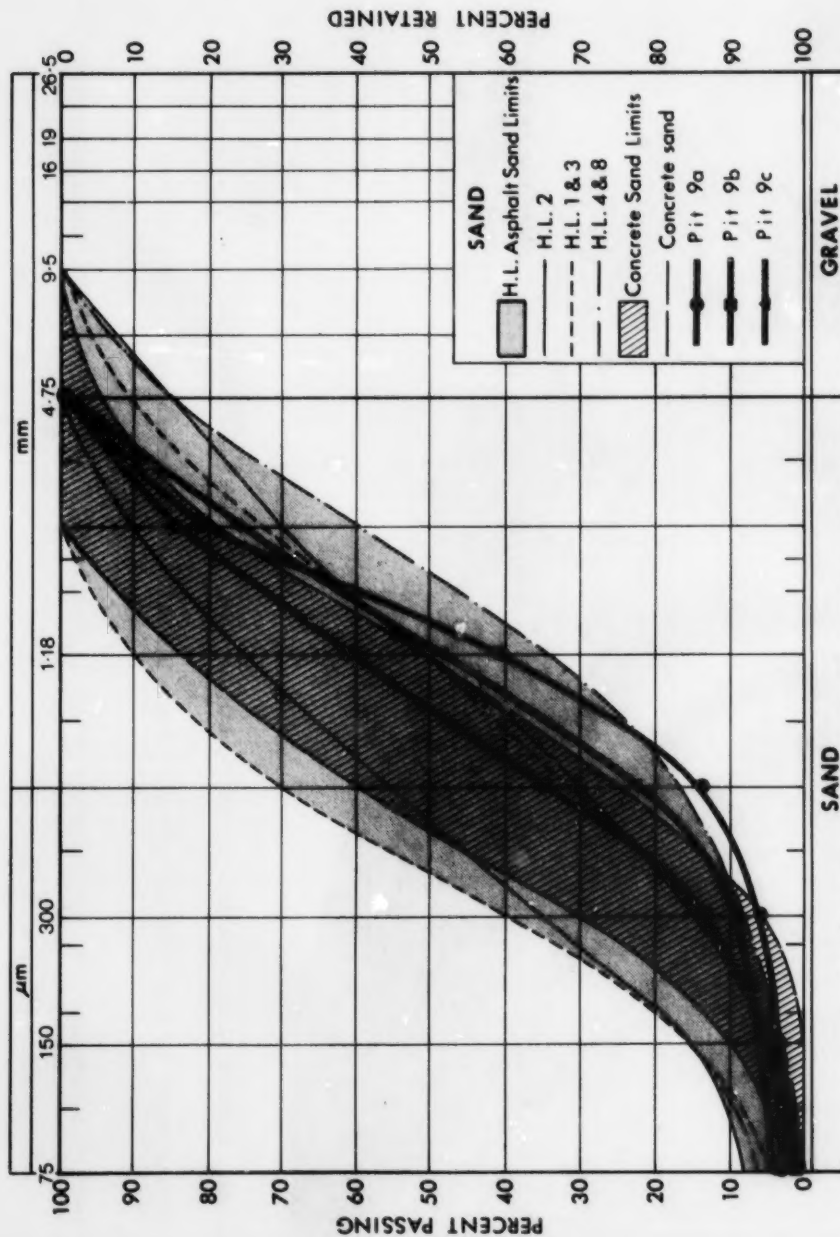


FIGURE 6b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1978 and 1005, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

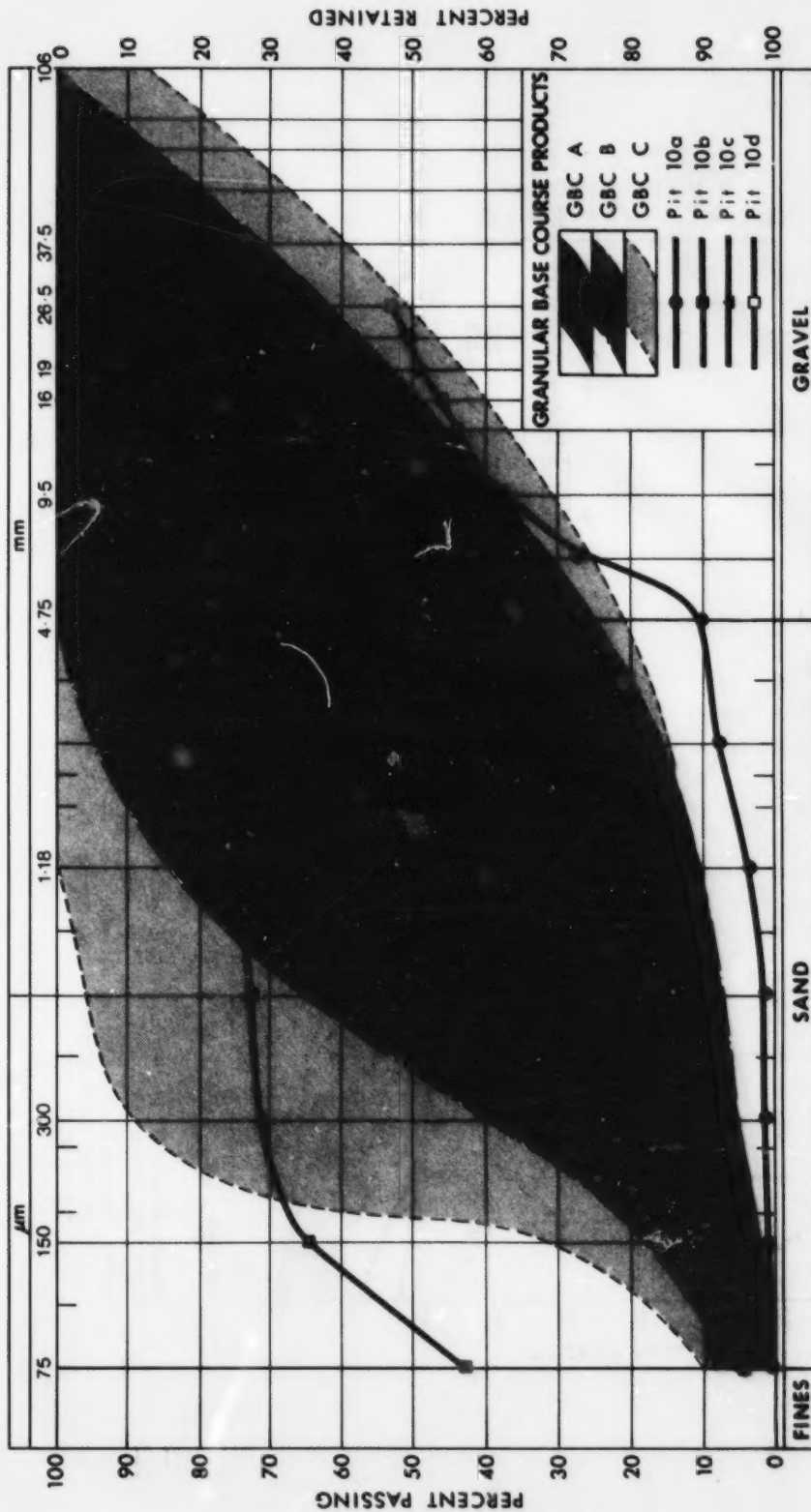


FIGURE 7a. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

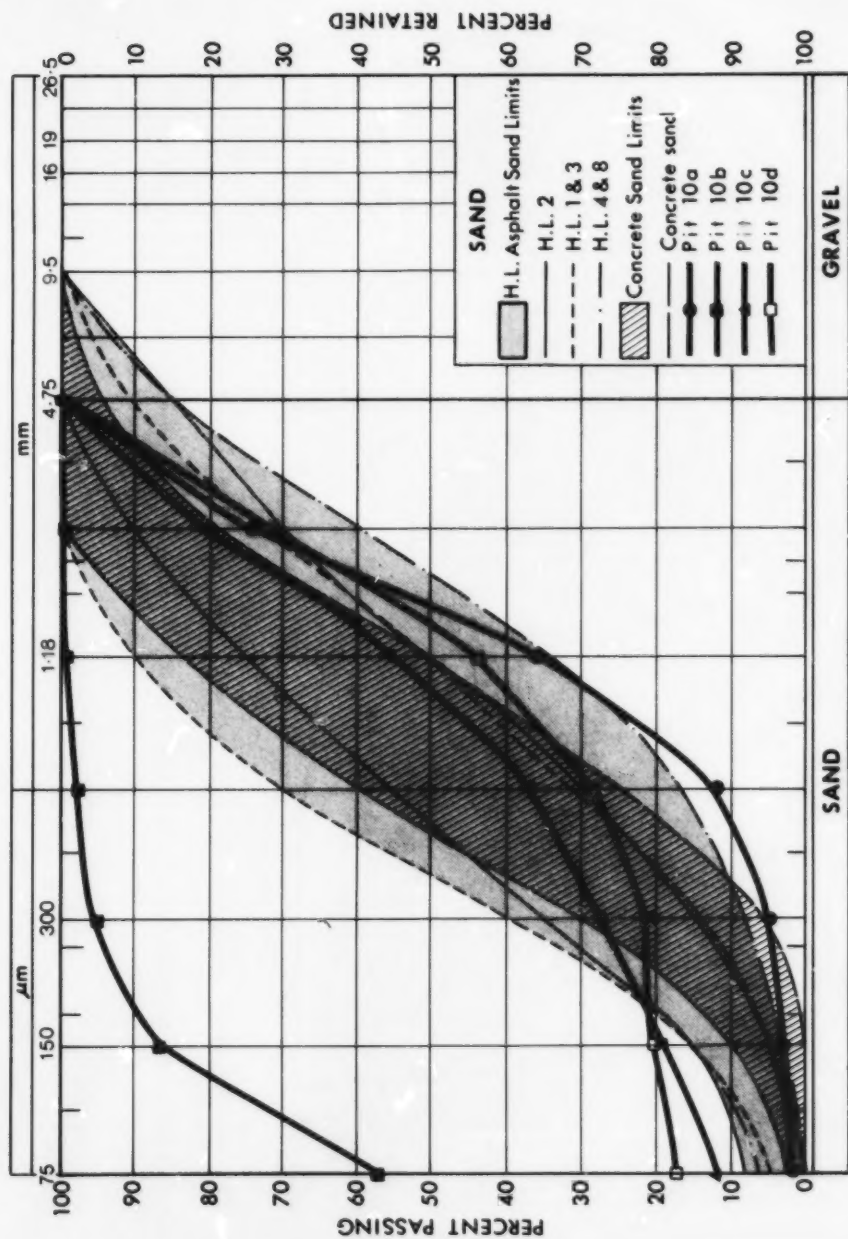


FIGURE 7b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

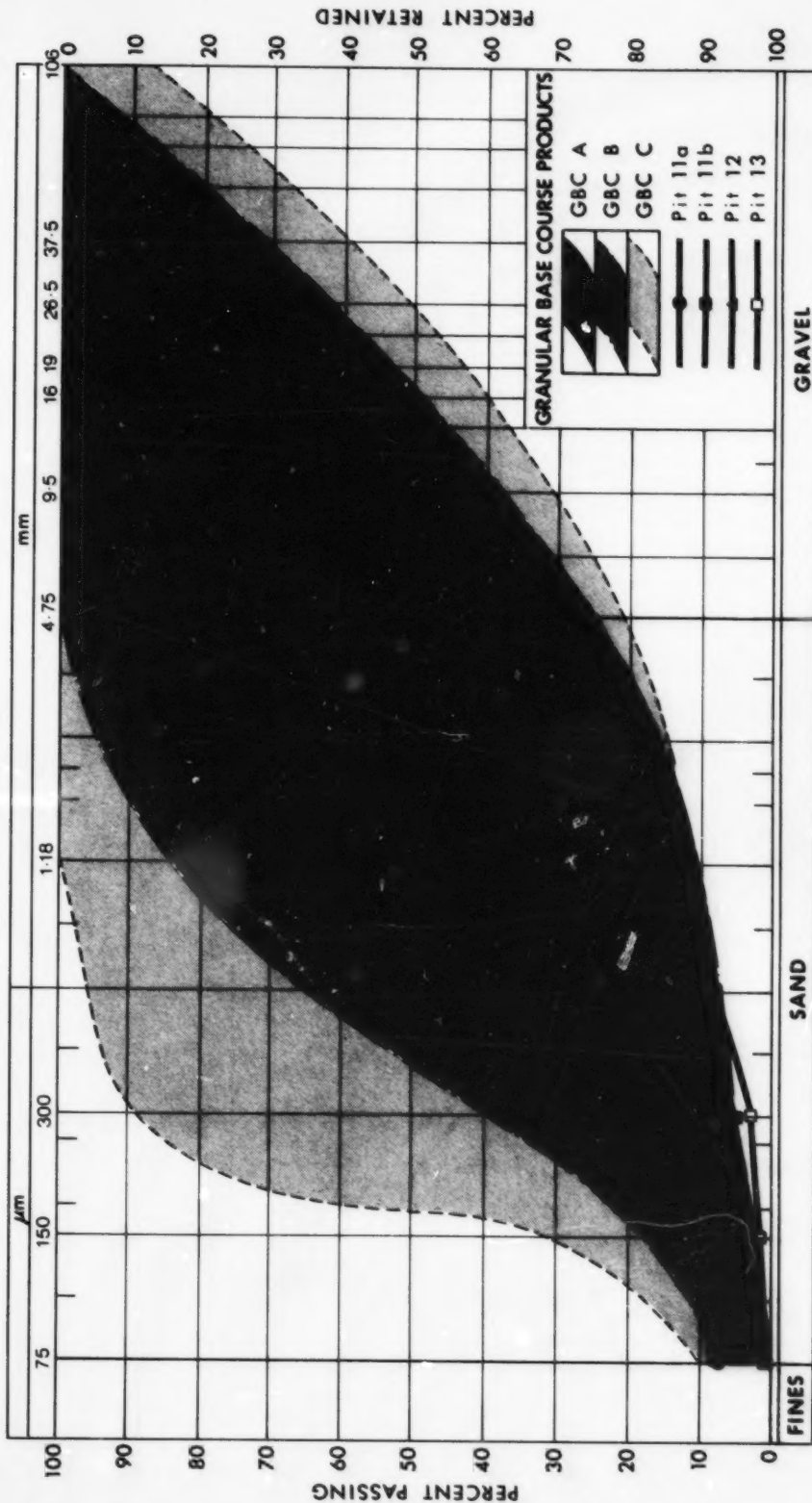


FIGURE 8a. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

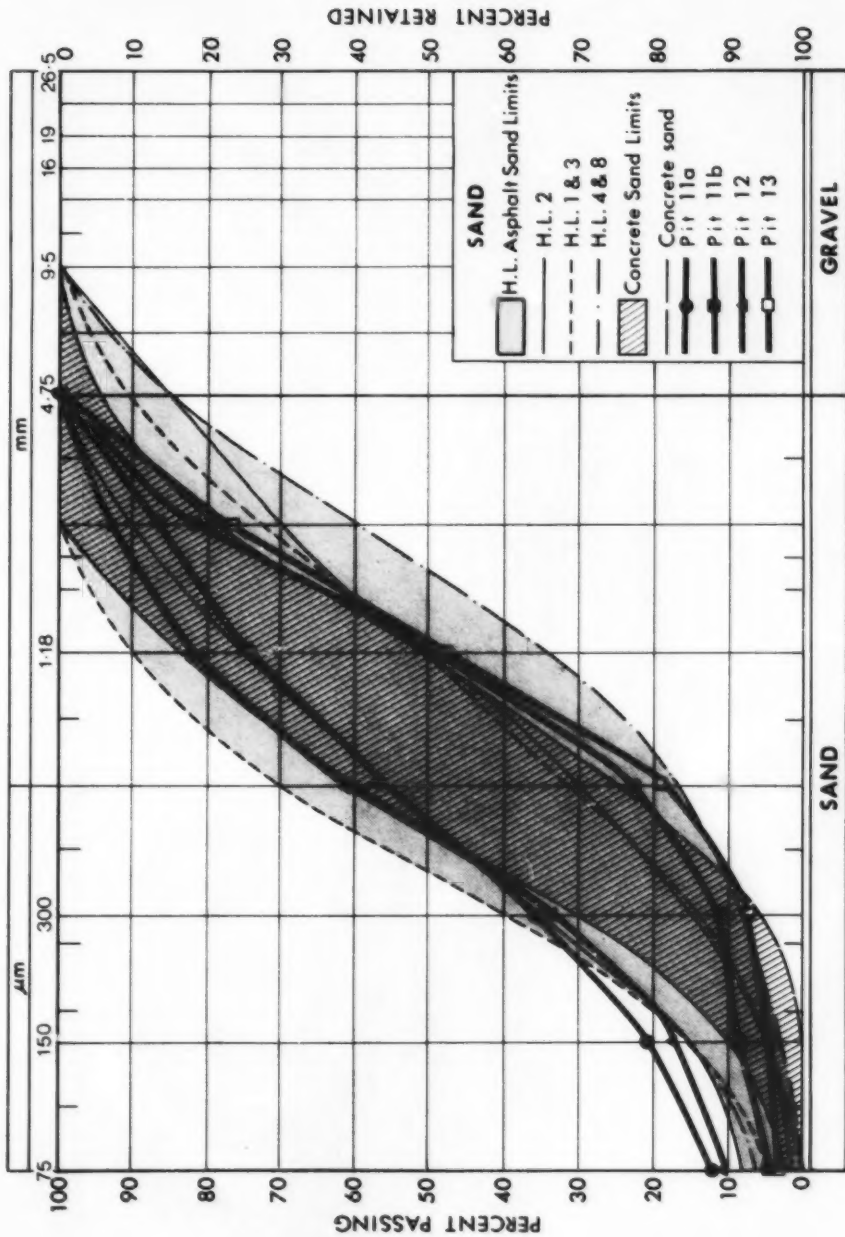


FIGURE 8b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

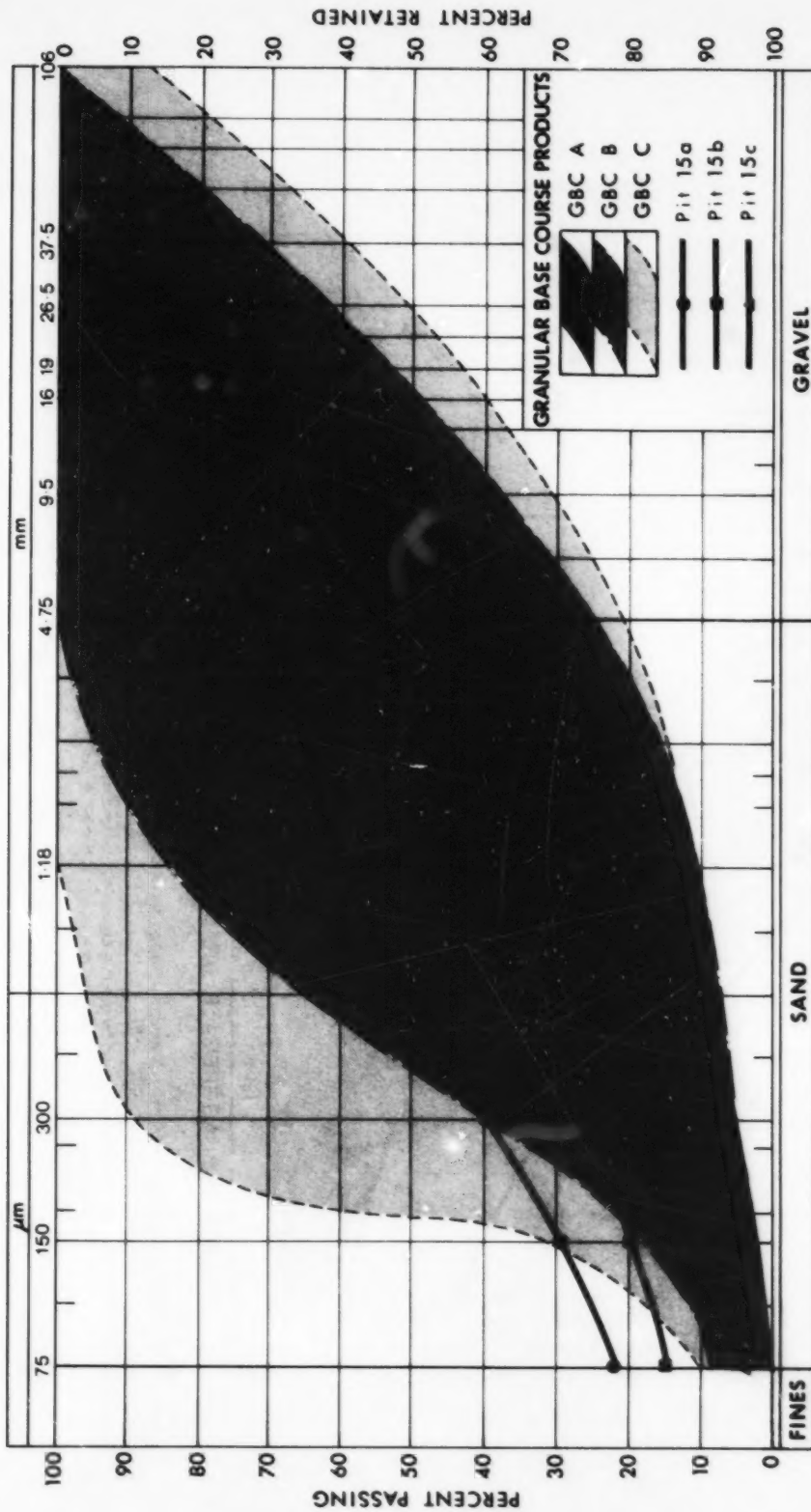


FIGURE 9a. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

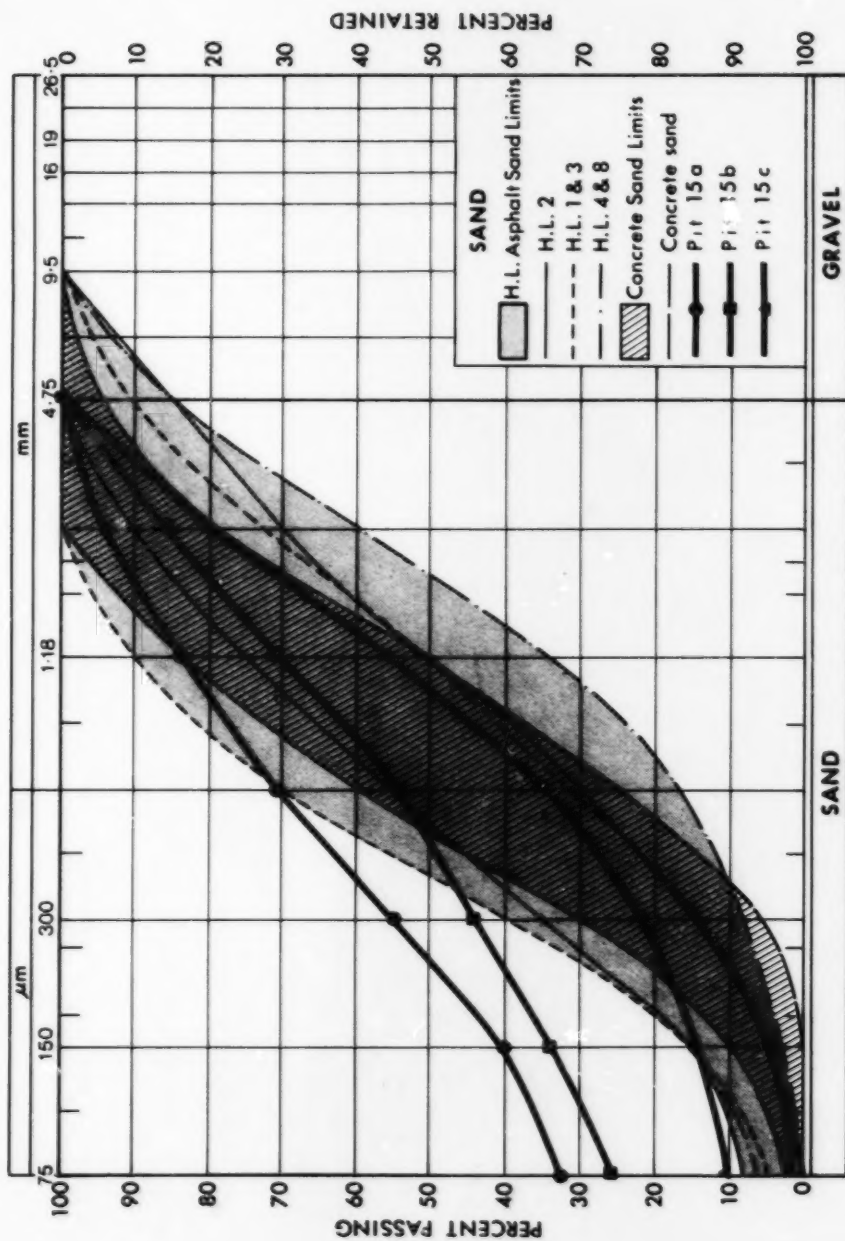


FIGURE 9b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

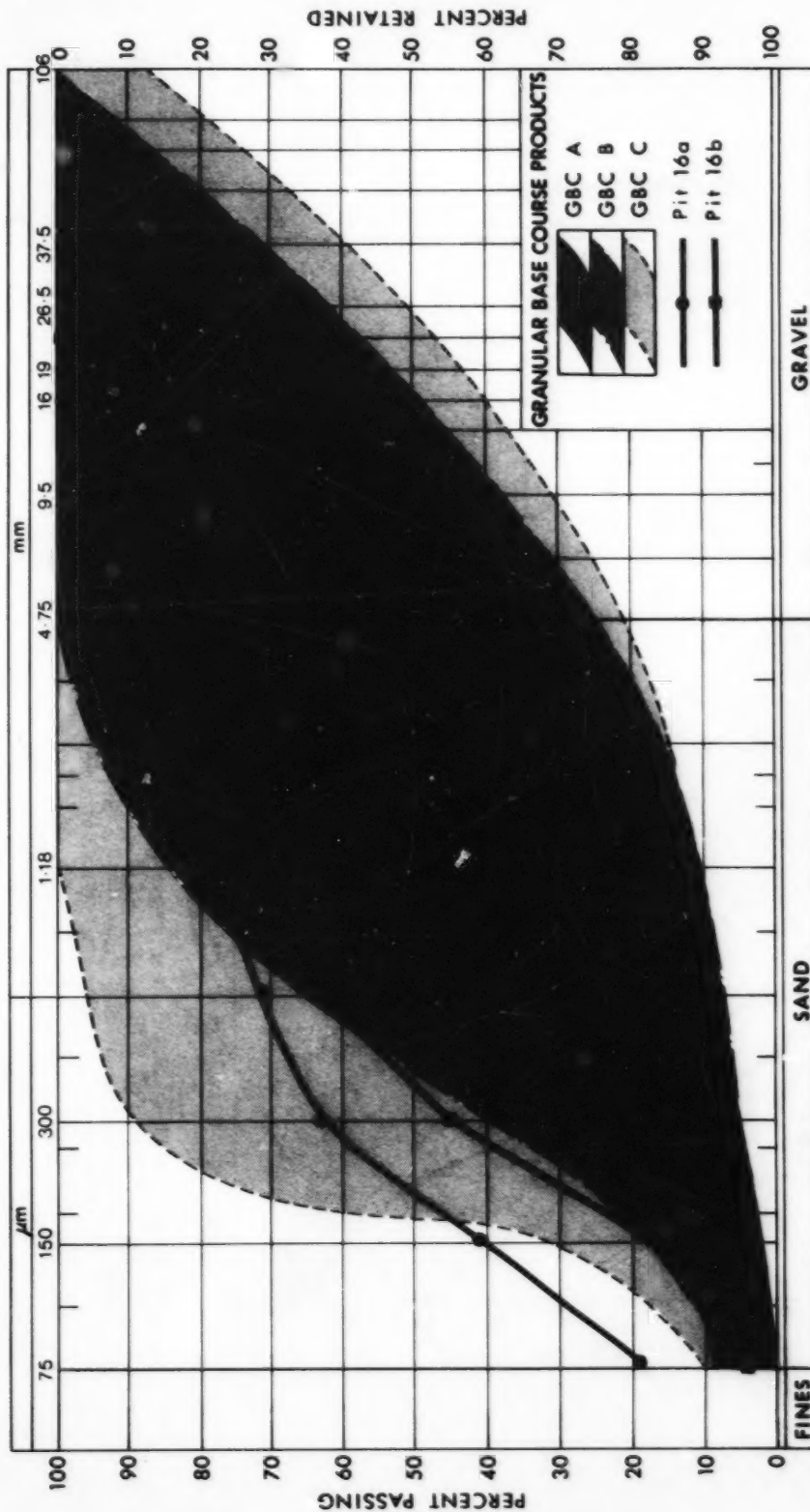


FIGURE 10a. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

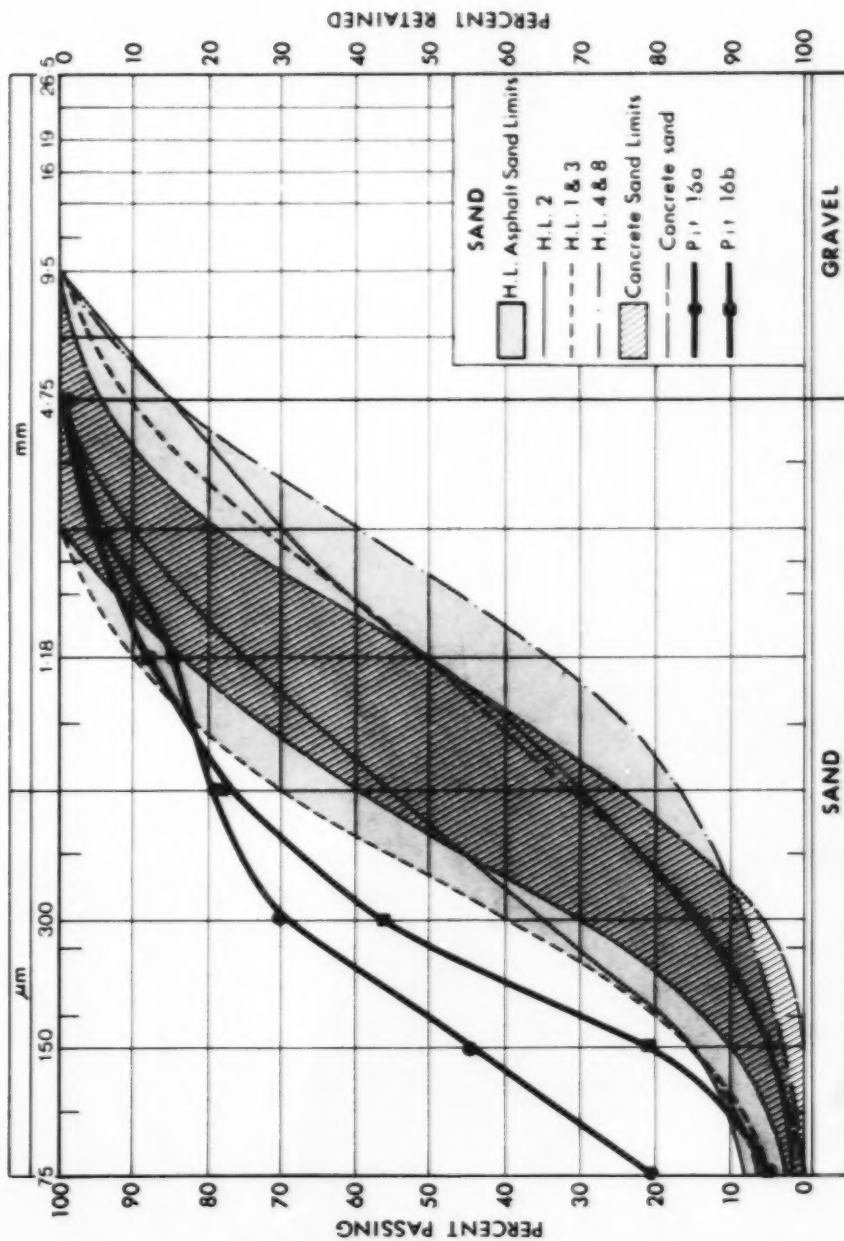


FIGURE 10b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

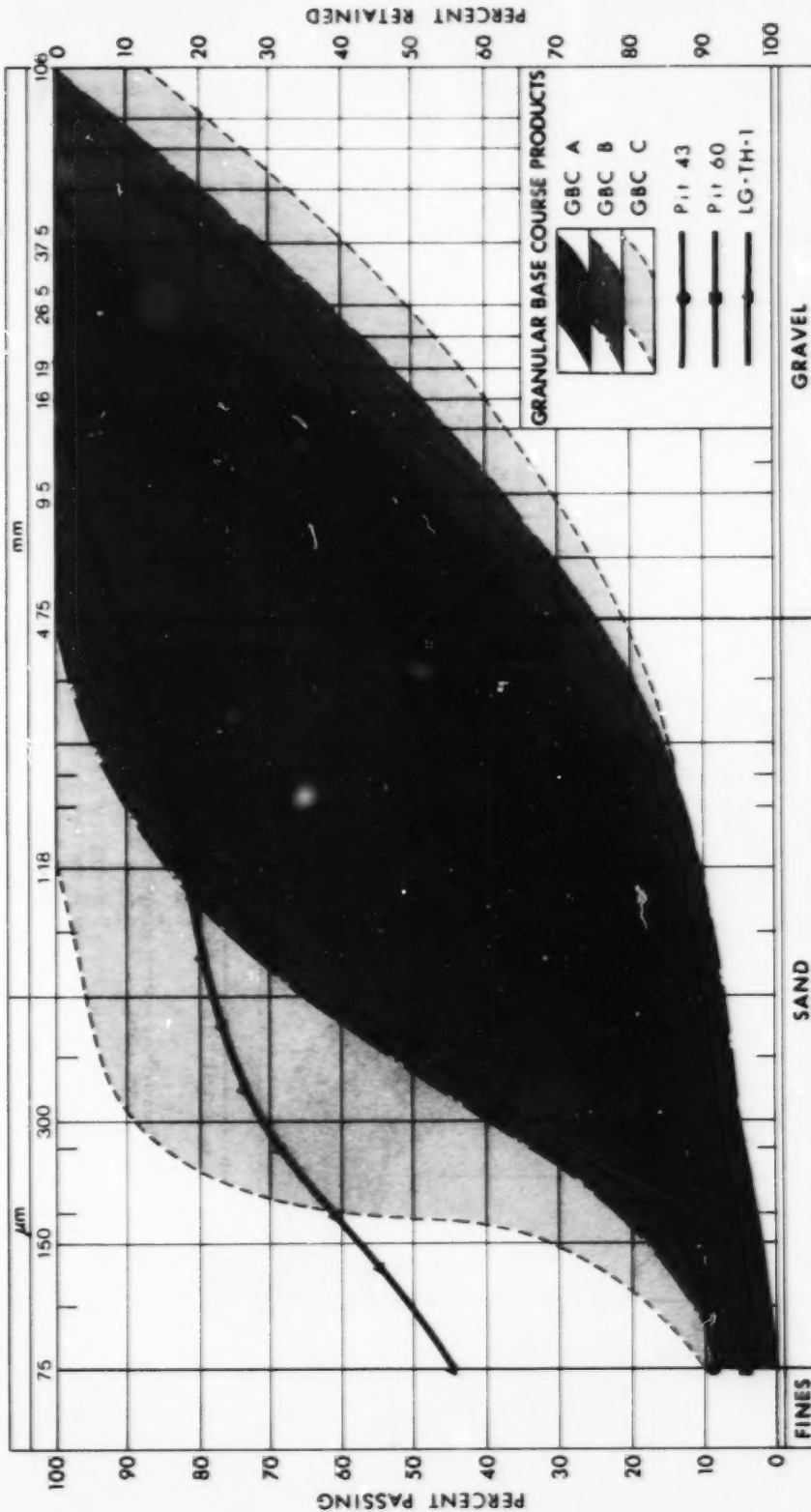


FIGURE 11a. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Form 1010, 1980)

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

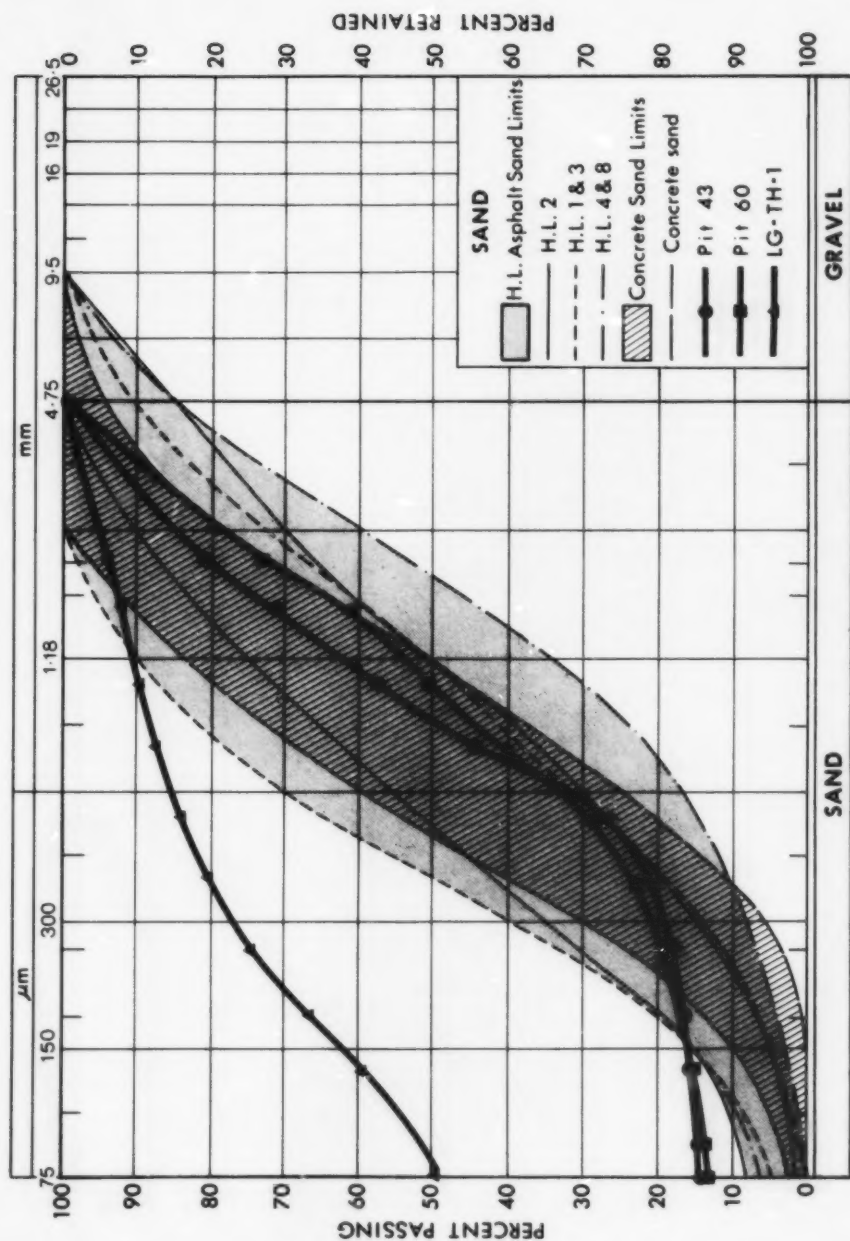


FIGURE 11b. AGGREGATE GRADING CURVES, LOGAN AND HIBBERT TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

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Appendix A — Suggested Additional Reading

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Appendix B — Glossary

Abrasion resistance: Tests such as the Los Angeles abrasion test are used to measure the ability of aggregate to resist crushing and pulverizing under conditions similar to those encountered in processing and use. Measuring resistance is an important component in the evaluation of the quality and prospective uses of aggregate. Hard, durable material is preferred for road building.

Absorption capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate.

Aggregate: Any hard, inert, construction material (sand, gravel, shells, slag, crushed stone or other mineral material) used for mixing in various-sized fragments with a cement or bituminous material to form concrete, mortar, etc., or used alone for road building or other construction. Synonyms include mineral aggregate and granular material.

Aggregate Abrasion Value: This test directly measures the resistance of aggregate to abrasion with silica sand and a steel disk. The higher the value, the lower the resistance to abrasion. For high quality asphalt surface course uses, values of less than 6 are desirable.

Alkali-aggregate reaction: A chemical reaction between the alkalis of portland cement and certain minerals found in rocks used for aggregate. Alkali-aggregate reactions are undesirable because they can cause expansion and cracking of concrete. Although perfectly suitable for building stone and asphalt applications, alkali-reactive aggregates should be avoided for structural concrete uses.

Beneficiation: Beneficiation of aggregates is a process or combination of processes which improves the quality (physical properties) of a mineral aggregate and is not part of the normal processing for a particular use, such as routine crushing, screening, washing or classification. Heavy media separation, jigging, or application of special crushers (e.g., "cage mill") are usually considered processes of beneficiation.

Blending: Required in cases of extreme coarseness, fineness, or other irregularities in the gradation of unprocessed aggregate. Blending is done with approved sand-sized aggregate in order to satisfy the gradation requirements of the material.

Bulk Relative Density: An aggregate with low relative density is lighter in weight than one with a high relative density. Low relative density aggregates (less than about 2.5) are often non-durable for many aggregate uses.

Cambrian: The first period of the Paleozoic Era, thought to have covered the time between 570 and 500 million years ago. The Cambrian precedes the Ordovician Period.

Clast: An individual constituent, grain or fragment of a sediment or rock, produced by the mechanical weathering of larger rock mass. Synonyms include particle and fragment.

Crushable aggregate: Unprocessed gravel containing a minimum of 35% coarse aggregate larger than the No. 4 sieve (4.75 mm) as well as a minimum of 20% greater than the 26.5 mm sieve.

Deleterious lithology: A general term used to designate those rock types which are chemically or physically unsuited for use as construction or road-building aggregates. Such lithologies as chert, shale, siltstone and sandstone may deteriorate rapidly when exposed to traffic and other environmental conditions.

Devonian: A period of the Paleozoic Era thought to have covered the span of time between 395 and 345 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest found in Ontario.

Dolostone: A carbonate sedimentary rock consisting chiefly of the mineral dolomite and containing relatively little calcite (dolostone is also known as dolomite).

Drift: A general term for all unconsolidated rock debris transported from one place and deposited in another, distinguished from underlying bedrock. In North America, glacial activity has been the dominant mode of transport and deposition of drift. Synonyms include overburden and surficial deposit.

Drumlin: A low, smoothly rounded, elongated hill, mound, or ridge composed of glacial materials. These landforms were formed beneath an advancing ice sheet, and were shaped by its flow.

Eolian: Pertaining to the wind, especially with respect to landforms whose constituents were transported and deposited by wind activity. Sand dunes are an example of an eolian landform.

Fines: A general term used to describe the size fraction of an aggregate which passes (is finer than) the No. 200 mesh screen (0.075 mm). Also described informally as "dirt", these particles are in the silt and clay size range.

Glacial lobe: A tongue-like projection from the margin of the main mass of an ice cap or ice sheet. During the Pleistocene Epoch several lobes of the Laurentide continental ice sheet occupied the Great Lakes basins. These lobes advanced then melted back numerous times during the Pleistocene, producing the complex arrangement of glacial material and landforms found in southern Ontario.

Gradation: The proportion of material of each particle size, or the frequency distribution of the various sizes which constitute a sediment. The strength, durability, permeability and stability of an aggregate depend to a great extent on its gradation. The size limits for different particles are as follows:

Boulder	more than 200 mm
Cobbles	75-200 mm
Coarse Gravel	26.5-75 mm
Fine Gravel	4.75-26.5 mm
Coarse Sand	2-4.75 mm
Medium Sand	0.425-2 mm
Fine Sand	0.075-0.425 mm
Silt, Clay	less than 0.075 mm

Granular base course: Components of the pavement structure of a road, which are placed on the subgrade and are designed to provide strength, stability and drainage, as well as support for surfacing materials. Several types have been defined: Granular Base Course A consists of crushed and processed aggregate and has relatively stringent quality standards in comparison to Granular Base Course B and C which are usually pit-run or other unprocessed aggregate.

Hot-laid (or asphaltic) aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course (HL 1, 3 and 4), or as binder course (HL 2 and 8) used to bind the surface course to the underlying granular base course.

Lithology: The description of rocks on the basis of such characteristics as colour, structure, mineralogic composition and grain size. Generally, the description of the physical character of a rock.

Los Angeles Abrasion and Impact Test: This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported, and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium sulphate soundness test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Meltwater channel: A drainage way, often terraced, produced by water flowing away from a melting glacier margin.

Ordovician: An early period of the Paleozoic Era thought to have covered the span of time between 500 and 435 million years ago.

Paleozoic era: One of the major divisions of the geologic time scale thought to have covered the time between 570 and 230 million years ago, the Paleozoic Era (or Ancient Life Era) is subdivided into six geologic periods, of which only four (Cambrian, Ordovician, Silurian and Devonian) can be recognized in southern Ontario.

Petrographic examination: Individual aggregate particles in a sample are divided into categories good, fair, poor, and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

Pleistocene: An epoch of the recent geological past including the time from approximately 2 million years ago to 7000 years ago. Much of the Pleistocene was characterized by extensive glacial activity and is popularly referred to as the "Great Ice Age".

Polished Stone Value: This test measures the frictional properties of aggregates after 6 hours of abrasion and polishing with an emery abrasive. The higher the PSV, the higher the frictional properties of the aggregate. Values less than 45 indicate marginal frictional properties, while values greater than 55 indicate excellent frictional properties.

Possible resource: Reserve estimates based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on assumed continuity or repetition for which there are reasonable geological indications.

Precambrian: The earliest geological period extending from the consolidation of the earth's crust to the beginning of the Cambrian.

Shale: A fine-grained, sedimentary rock formed by the consolidation of clay, silt or mud and characterized by well developed bedding planes, along which the rock breaks readily into thin layers. The term shale is also commonly used for fissile claystone, siltstone and mudstone.

Silurian: An early period of the Paleozoic Era thought to have covered the time between 435 and 395 million years ago. The Silurian follows the Ordovician Period and precedes the Devonian Period.

Soundness: The ability of the components of an aggregate to withstand the effects of various weathering processes and agents. Unsound lithologies are subject to disintegration caused by the expansion of absorbed solutions. This may seriously impair the performance of road-building and construction aggregates.

Till: Unsorted and unstratified rock debris, deposited directly by glaciers, and ranging in size from clay to large boulders.

Wisconsinan: Pertaining to the last glacial period of the Pleistocene Epoch in North America. The Wisconsinan began approximately 100 000 years ago and ended approximately 7000 years ago. The glacial deposits and landforms of southern Ontario are predominantly the result of glacial activity during the Wisconsinan Stage.

Appendix C — Geology of Sand and Gravel Deposits

The type, distribution, and extent of sand and gravel deposits in southern Ontario are the result of extensive glacial and glacially influenced activity in Wisconsin time during the Pleistocene Epoch, approximately 100 000 to 7000 years ago. The deposit types reflect the different depositional environments that existed during the melting and retreat of the continental ice masses, and can readily be differentiated on the basis of their morphology, structure, and texture. The deposit types are described below.

GLACIOFLUVIAL DEPOSITS

These deposits can be divided into two broad categories: those that were formed in contact with (or in close proximity to) glacial ice, and those that were deposited by meltwaters carrying materials beyond the ice margin.

Ice-Contact Terraces (ICT): These are glaciofluvial features deposited between the glacial margin and a confining topographic high, such as the side of a valley. The structure of the deposits may be similar to that of outwash deposits, but in most cases the sorting and grading of the material is more variable and the bedding is discontinuous because of extensive slumping. The probability of locating large amounts of crushable aggregate is moderate, and extraction may be expensive because of the variability of the deposits both in terms of quality and grain size distribution.

Kames (K): Kames are defined as mounds of poorly sorted sand and gravel deposited by meltwater in depressions or fissures on the ice surface or at its margin. During glacial retreat, the melting of supporting ice causes collapse of the deposits, producing internal structures characterized by bedding discontinuities. The deposits consist mainly of irregularly bedded and cross-bedded, poorly sorted sand and gravel. The present forms of the deposits include single mounds, linear ridges (crevasse fillings) or complex groups of landforms. The latter are occasionally described as "undifferentiated ice-contact stratified drift" (IC) when detailed subsurface information is unavailable. Since kames commonly contain large amounts of fine-grained material and are characterized by considerable variability, there is generally a low to moderate probability of discovering large amounts of good quality, crushable aggregate. Extractive problems encountered in these deposits are mainly the excessive variability of the aggregate and the rare presence of excess fines (silt- and clay-sized particles).

Eskers (E): Eskers are narrow, sinuous ridges of sand and gravel deposited by meltwaters flowing in tunnels within or at the base of glaciers, or in channels on the ice surface. Eskers vary greatly in size. Many, though not all eskers, consist of a central core of poorly sorted and stratified gravel characterized by a wide range in grain size. The core material is often draped on its flanks by

better sorted and stratified gravel. The deposits have a high probability of containing a large proportion of crushable aggregate, and since they are generally built above the surrounding ground surface, are convenient extraction sites. For these reasons esker deposits have been traditional aggregate sources throughout Ontario, and are significant components of the total resources of many areas.

Some planning constraints and opportunities are inherent in the nature of the deposits. Because of their linear nature, the deposits commonly extend across several property boundaries leading to unorganized extractive development at numerous small pits. On the other hand, because of their form, eskers can be easily and inexpensively extracted and are amenable to rehabilitation and sequential land use.

Undifferentiated Ice-Contact Stratified Drift (IC): This designation may include deposits from several ice-contact, depositional environments which usually form extensive, complex landforms. It is not feasible to identify individual areas of coarse-grained material within such deposits because of their lack of continuity and grain size variability. They are given a qualitative rating based on existing pit and other subsurface data.

Outwash (OW): Outwash deposits consist of sand and gravel laid down by meltwaters beyond the margin of the ice lobes. The deposits occur as sheets or as terraced valley fills (valley trains) and may be very large in extent and thickness. Well developed outwash deposits have good horizontal bedding and are uniform in grain size distribution. Outwash deposited near the glacier's margin is much more variable in texture and structure. The probability of locating useful crushable aggregates in outwash deposits is moderate to high depending on how much information on size, distribution and thickness is available.

Subaqueous Fan (SF): Subaqueous fans are formed within or near the mouths of meltwater conduits when sediment laden meltwaters are discharged into a standing body of water. The geometry of the resulting deposit is fan or lobe shaped. Several of these lobes may be joined together to form a larger, continuous sedimentary body. Internally, subaqueous fans consist of stratified sands and gravels which may exhibit wide variations in grain size distribution. As these features were deposited under glacial lake waters, silt and clay which settled out of these lakes may be associated in varying amounts with these deposits. The variability of the sediments and presence of fines are the main extractive problems associated with these deposits.

Alluvium (AL): Alluvium is a general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during postglacial time by a stream as sorted or semi-sorted sediment, on its bed or on its floodplain. The probability of locating large amounts of crushable aggregate in alluvial deposits is low, and they have gen-

erally low value because of the presence of excess silt- and clay-sized material. There are few large postglacial alluvium deposits in Ontario.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine Beach Deposits (LB): These are relatively narrow, linear features formed by wave action at the shores of glacial lakes that existed at various times during the deglaciation of southern Ontario. Well developed lacustrine beaches are usually less than 20 feet (6 m) thick. The aggregate is well sorted and stratified and sand-sized material commonly predominates. The composition and size distribution of the deposit depends on the nature of the source material. The probability of obtaining crushable aggregate is high when the material is developed from coarse-grained materials such as a stony till, and low when developed from fine-grained materials. Beaches are relatively narrow, linear deposits, so that extractive operations are often numerous and extensive.

Glaciolacustrine Deltas (LD): These features were formed where streams or rivers of glacial meltwater flowed into lakes and deposited their suspended sediment. In southern Ontario such deposits tend to consist mainly of sand and abundant silt. However, in near-ice and ice-contact positions, coarse material may be present. Although deltaic deposits may be large, the probability of obtaining coarse material is generally low.

Glaciolacustrine Plains (LP): The nearly level surface marking the floor of an extinct glacial lake. The sediments which form the plain are predominantly fine to medium sand, silt, and clay, and were deposited in rela-

tively deep water. Lacustrine deposits are generally of low value as aggregate sources because of their fine grain size and lack of crushable material. In some aggregate-poor areas, lacustrine deposits may constitute valuable sources of fill and some granular base course aggregate.

GLACIAL DEPOSITS

End Moraines (EM): These are belts of glacial drift deposited at, and parallel to, glacier margins. End moraines commonly consist of ice-contact stratified drift and in such instances are usually called kame moraines. Kame moraines commonly result from deposition between two glacial lobes (interlobate moraines). The probability of locating aggregates within such features is moderate to low. Exploration and development costs are high. Moraines may be very large and contain vast aggregate resources, but the location of the best areas within the moraine is usually poorly defined.

EOLIAN DEPOSITS

Windblown Deposits (WD): Windblown deposits are those formed by the transport and deposition of sand by winds. The form of the deposits ranges from extensive, thin layers to well developed linear and crescentic ridges known as dunes. Most windblown deposits in southern Ontario are derived from, and deposited on, pre-existing lacustrine sand plain deposits. Windblown sediments almost always consist of fine to coarse sand and are usually well sorted. The probability of locating crushable aggregate in windblown deposits is very low.

Appendix D — Geology of Bedrock Deposits

The purpose of this appendix is to familiarize the reader with the general bedrock geology of southern Ontario (Figure D1), and the potential uses of the various bedrock formations where known. The reader is cautioned against using this information for more specific purposes. The stratigraphic chart (Figure D2) is intended only to illustrate the stratigraphic sequences in particular geographic areas and should not be used as a regional correlation table.

The following description is arranged in ascending stratigraphic order, on a group and formation basis. Precambrian rocks are not discussed. Additional stratigraphic information is included for some formations where necessary. The publications and maps of the Ontario Geological Survey and the Geological Survey of Canada should be referred to for more detailed information. The composition, thickness, and uses of the for-

mations are discussed. If a formation may be suitable for use as aggregate and aggregate suitability test data is available, the data has been included in the form of ranges. The following short forms have been used in presenting this data: PSV = Polished Stone Value, AAV = Aggregate Abrasion Value, $MgSO_4$ = Magnesium Sulphate Soundness Test (loss in percent), LA = Los Angeles Abrasion and Impact Test (loss in percent), Absn = Absorption (percent), BRD = Bulk Relative Density, PN (Asphalt & Concrete) = Petrographic Number for Asphalt and Concrete use.

The ranges are intended as a guide only and care should be exercised in extrapolating the information to specific situations. Aggregate suitability test data has been provided by the Ontario Ministry of Transportation.

Covey Hill Formation (Cambrian)

STRATIGRAPHY: lower formation of the Potsdam Group. **COMPOSITION:** interbedded non-calcareous feldspathic conglomerate and sandstone. **THICKNESS:** 0 to 45 feet (0 to 14 m). **USES:** has been quarried for aggregate in South Burgess Township, Leeds County.

Nepean Formation (Cambro-Ordovician)

STRATIGRAPHY: upper formation of the Potsdam Group. **COMPOSITION:** thin-bedded to massive quartz sandstone with some conglomerate interbeds and rare shaly partings. **THICKNESS:** 0 to 100 feet (0 to 30 m). **USES:** suitable as dimension stone; quarried at Philippsville and Forfar for silica sand; alkali-silica reactive in Portland cement concrete. **AGGREGATE SUITABILITY TESTING:** PSV = 54-68, AAV = 4-15, $MgSO_4$ = 9-32, LA = 44-90, Absn = 1.6-2.6, BRD = 2.38-2.50, PN (Asphalt & Concrete) = 130-140.

March Formation (Lower Ordovician)

STRATIGRAPHY: lower formation of the Beekmantown Group. **COMPOSITION:** interbedded quartz sandstone, dolomitic quartz sandstone, sandy dolostone and dolostone. **THICKNESS:** 60 to 197 feet (18 to 60 m). **USES:** quarried extensively for aggregate in area of subcrop and outcrop; alkali-silica reactive in Portland cement concrete; lower part of formation is an excellent source of skid-resistant aggregate; suitable for use as facing stone and paving stone. **AGGREGATE SUITABILITY TESTING:** PSV = 55-60, AAV = 4-6, $MgSO_4$ = 1-17, LA = 15-38, Absn = 0.5-0.9, BRD = 2.61-2.65, PN (Asphalt & Concrete) = 110-150.

Oxford Formation (Lower Ordovician)

STRATIGRAPHY: upper formation of the Beekmantown Group. **COMPOSITION:** thin- to thick-bedded, microcrystalline to medium-crystalline, grey dolostone with thin shaly interbeds. **THICKNESS:** 200 to 335 feet (61 to 102 m). **USES:** quarried in the Brockville and Smith Falls areas and south of Ottawa for use as aggregate. **AGGREGATE SUITABILITY TESTING:** PSV = 47-48, AAV = 7-8, $MgSO_4$ = 1-4, LA = 18-23, Absn = 0.7-0.9, BRD = 2.74-2.78, PN (Asphalt & Concrete) = 105-120.

Rockcliffe Formation (Middle Ordovician)

STRATIGRAPHY: divided into lower member and upper (St. Martin) member. **COMPOSITION:** interbedded quartz sandstone and shale; interbedded shaly bioclastic limestone and shale predominating in upper member to the east. **THICKNESS:** 0 to 410 feet (0 to 125 m). **USES:** upper member has been quarried east of Ottawa for aggregate; lower member has been used as crushed stone; some high purity limestone beds in upper member may be suitable for use as fluxing stone and in lime production. **AGGREGATE SUITABILITY TESTING:** PSV = 58-63, AAV = 10-11, $MgSO_4$ = 12-40, LA = 25-28, Absn = 1.8-1.9, BRD = 2.55-2.62, PN (Asphalt & Concrete) = 122-440.

Shadow Lake Formation (Middle Ordovician)

STRATIGRAPHY: eastern Ontario - the basal unit of the Ottawa Group; central Ontario - overlain by the Simcoe Group. **COMPOSITION:** in eastern Ontario - silty and sandy dolostone with shale partings and minor interbeds of sandstone; in central Ontario - conglomer-

ates, sandstones, and shales. **THICKNESS:** eastern Ontario - 7 to 10 feet (2 to 3 m); central Ontario - 0 to 40 feet (0 to 12 m). **USES:** potential source of decorative stone; very limited value as aggregate source.

Gull River Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and Ottawa Group (eastern Ontario). In central and eastern Ontario the formation is subdivided into upper and lower members; west of Lake Simcoe it is presently subdivided into upper, middle and lower members. **COMPOSITION:** in central and eastern Ontario the lower member consists of alternating units of limestone, dolomitic limestone, and dolostone, the upper member consists of thin-bedded limestones with thin shale partings; west of Lake Simcoe the lower member is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone, whereas the upper and middle members are dense microcrystalline limestones with argillaceous dolostone interbeds. **THICKNESS:** 23 to 204 feet (7 to 62 m). **USES:** quarried in the Lake Simcoe, Kingston, Ottawa, and Cornwall areas for crushed stone; rock from certain layers in eastern and central Ontario has proven to be alkali-reactive when used in Portland cement concrete (alkali-carbonate reaction). **AGGREGATE SUITABILITY TESTING:** PSV = 41-49, AAV = 8-12, $MgSO_4$ = 3-13, LA = 18-28, Absn = 0.3-0.9, BRD = 2.68-2.73, PN (Asphalt & Concrete) = 100-153.

Bobcaygeon Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and the Ottawa Group (eastern Ontario); subdivided into upper, middle and lower members; members in eastern and central Ontario are approximately equivalent. **COMPOSITION:** homogeneous, massive to thin-bedded fine-crystalline limestone with numerous shaly partings in the middle member. **THICKNESS:** 80 to 285 feet (24 to 87 m). **USES:** quarried at Brechin, Marysville, and in the Ottawa area for crushed stone; generally suitable for use as granular base course aggregate; rock from certain layers has been found to be alkali-reactive when used in Portland cement concrete (alkali-silica reaction). **AGGREGATE SUITABILITY TESTING:** PSV = 47-51, AAV = 14-23, $MgSO_4$ = 1-40, LA = 18-32, Absn = 0.3-2.4, BRD = 2.5-2.69, PN (Asphalt & Concrete) = 100-320.

Verulam Formation (Middle Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa Groups. **COMPOSITION:** fossiliferous, pure to argillaceous limestone interbedded with calcareous shale. **THICKNESS:** 105 to 230 feet (32 to 70 m). **USES:** quarried at Picton and Bath for use in cement manufacture; quarried for aggregate in Mara Township, Simcoe County and in the Belleville-Kingston area; may be unsuitable

for use as aggregate in some areas because of its high shale content. **AGGREGATE SUITABILITY TESTING:** PSV = 43-44, AAV = 9-13, $MgSO_4$ = 4-45, LA = 22-29, Absn = 0.4-2.1, BRD = 2.59-2.70, PN (Asphalt & Concrete) = 120-255.

Lindsay Formation (Middle and Upper Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa Groups; in eastern Ontario is divisible into an unnamed lower member and the Eastview Member; in central Ontario is divisible into the Collingwood Member (equivalent to portions of the Eastview Member) and a lower member. **COMPOSITION:** in eastern Ontario the lower member is interbedded, very fine- to coarse-crystalline limestone with undulating shale partings and interbeds of dark grey calcareous shale, whereas the Eastview Member is an interbedded dark grey to dark brown calcareous shale and very fine- to fine-crystalline, petroliferous limestone; in central Ontario Collingwood Member is a black, calcareous shale whereas the lower member is a very fine- to coarse-crystalline, thin-bedded limestone with very thin, undulating shale partings. **THICKNESS:** 82 to 200 feet (25 to 61 m). **USES:** in eastern Ontario the lower member is used extensively for aggregate production; in central Ontario it is quarried at Picton, Ogden Point and Bowmanville for cement; may be suitable or unsuitable for use as concrete and asphalt aggregate. **AGGREGATE SUITABILITY TESTING:** $MgSO_4$ = 2-47, LA = 20-28, Absn = 0.4-1.3, BRD = 2.64-2.70, PN (Asphalt & Concrete) = 110-215.

Blue Mountain and Billings Formations (Upper Ordovician)

STRATIGRAPHY: central Ontario - Blue Mountain Formation includes the upper and middle members of the former Whitby Formation; eastern Ontario - Billings Formation is equivalent to part of the Blue Mountain Formation. **COMPOSITION:** the Blue Mountain Formation is blue-grey, noncalcareous shale; Billings Formation is dark grey to black, noncalcareous to slightly calcareous, pyritiferous shale with dark grey limestone laminae and grey siltstone interbeds. **THICKNESS:** Blue Mountain Formation - 140 to 200 feet (43 to 61 m); Billings Formation - 0 to 205 feet (0 to 62 m). **USES:** Billings Formation may be a suitable source for structural clay products and expanded aggregate; Blue Mountain Formation may be suitable for structural clay products.

Georgian Bay and Carlsbad Formations (Upper Ordovician)

COMPOSITION: in central Ontario the Georgian Bay Formation is composed of interbedded limestone and shale; in eastern Ontario the Carlsbad Formation is composed of interbedded shale, siltstone and bioclastic limestone; **THICKNESS:** Georgian Bay Formation is 300 to 560 feet (91 to 170 m); Carlsbad Formation - 0 to 610 feet (0 to 186 m). **USES:** Georgian Bay Formation is

used by several producers in Metropolitan Toronto area to produce brick and structural tile, as well as for making Portland cement; at Streetsville, expanded shale was used in the past to produce lightweight aggregate; Carlsbad Formation is used as a source material for brick and tile manufacturing, has potential as a lightweight expanded aggregate.

Queenston Formation (Upper Ordovician)

COMPOSITION: red, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding. THICKNESS: 400 to 500 feet (122 to 152 m). USES: there are several large quarries developed in the Queenston Formation in the Toronto-Hamilton region and one at Russell, near Ottawa; all extract shale for brick manufacturing; the Queenston Formation is the most important source material for brick manufacture in Ontario.

Whirlpool Formation (Lower Silurian)

STRATIGRAPHY: lower formation in the Cataract Group in the Niagara Peninsula and the Niagara Escarpment as far north as Duntroon. COMPOSITION: massive, medium- to coarse-grained, argillaceous white to light grey quartz sandstone with thin grey shale partings. THICKNESS: 0 to 25 feet (0 - 8 m). USES: building stone, flagstone.

Manitoulin Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs north of Stoney Creek. COMPOSITION: thin-bedded, blue-grey to buff-brown dolomitic limestones and dolostones. THICKNESS: 0 to 75 feet (0 to 23 m). USES: extracted for crushed stone in St. Vincent Township, Grey County, and for decorative stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: no data.

Cabot Head Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs throughout southern Ontario, south and north of the Niagara Escarpment. COMPOSITION: green, grey and red shales. THICKNESS: 50 to 60 feet (15 to 18 m); USES: potential source of coated lightweight aggregate and raw material for use in manufacture of brick and tile; lack of suitable exposures has limited its use.

Grimsby Formation

STRATIGRAPHY: upper formation of the Cataract Group, is identified on the Niagara Peninsula as far north as Clappison's Corners. COMPOSITION: inter-bedded sandstone and shale, mostly red. THICKNESS: 0 to 50 feet (0 to 15 m). USES: no present uses.

Thorold Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on the Niagara Peninsula. COMPOSITION: thick-bedded quartz sandstone. THICKNESS: 7 to 10 feet (2 - 3 m). USES: no present uses.

Neagha Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on the Niagara Peninsula. COMPOSITION: dark grey to green shale with minor interbedded limestone. THICKNESS: 0 to 5 feet (0 to 2 m). USES: no present uses.

Dyer Bay Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: highly fossiliferous, impure dolostone. THICKNESS: 0 to 20 feet (0 to 6 m). USES: no present uses.

Wingfield Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: olive green to grey shale with dolostone interbeds. THICKNESS: 0 to 36 feet (0 to 11 m). USES: no present uses.

St. Edmund Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula, upper portion previously termed the Mindemoya Formation. COMPOSITION: pale grey to buff brown, micro- to medium-crystalline, thin- to medium-bedded dolostone. THICKNESS: 0 to 85 feet (0 to 26 m). USES: quarried for fill and crushed stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: $MgSO_4 = 1-2$, $LA = 19-21$, $Absn = 6-0.7$, $BRD = 2.78-2.79$, PN (Asphalt & Concrete) = 105.

Fossil Hill and Reynales Formations (Middle Silurian)

STRATIGRAPHY: part of Clinton Group; Fossil Hill Formation occurs in the northern part of the Niagara Escarpment and is approximately equivalent in part, to the Reynales Formation which occurs on the Niagara Peninsula and the Escarpment, as far north as the Forks of the Credit. COMPOSITION: Fossil Hill Formation is fine- to coarse-crystalline dolostone with high silica content; Reynales Formation is thin- to thick-bedded shaly dolostone and dolomitic limestone. THICKNESS: Fossil Hill Formation - 20 to 85 feet (6 to 26 m); Reynales Formation - 0 to 10 feet (0 to 3 m). USES: both formations quarried for aggregate with overlying Amabel and Lockport Formations. AGGREGATE SUITABILITY TESTING: (Fossil Hill Formation on Manitoulin Island) $MgSO_4 = 41$, $LA = 29$, $Absn = 4.1$, $BRD = 2.45$, PN (Asphalt & Concrete) = 370.

Irondequoit Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group on the Niagara Peninsula south of Waterdown. COMPOSITION: massive, coarse-crystalline crinoidal limestone. THICKNESS: 0 to 7 feet (0 to 2 m). USES: not significantly utilized.

Rochester Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group along the Niagara Peninsula. COMPOSITION: black to dark grey calcareous shale with numerous limestone lenses. THICKNESS: 15 to 60 feet (5 to 18 m). USES: not significantly utilized. AGGREGATE SUITABILITY TESTING: PSV = 69, AAV = 17, $MgSO_4$ = 95, LA = 19, Absn = 2.2, BRD = 2.67, PN (Asphalt & Concrete) = 400.

Decew Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group south of Waterdown along the Niagara Peninsula. COMPOSITION: sandy to shaly dolomitic limestone and dolostone. THICKNESS: 0 to 15 feet (0 to 5 m). USES: too shaly for high quality uses, but is quarried along with Lockport Formation in places. AGGREGATE SUITABILITY TESTING: PSV = 67, AAV = 15, $MgSO_4$ = 55, LA = 21, Absn = 2.2, BRD = 2.66, PN (Asphalt & Concrete) = 255.

Lockport and Amabel Formations (Middle Silurian)

STRATIGRAPHY: Lockport Formation occurs from Waterdown to Niagara Falls, subdivided into 3 formal members: Gasport, Goat Island and Eramosa Members and an informal member (the "Vinemount shale beds"); the stratigraphically equivalent Amabel Formation, found from Waterdown to Cockburn Island, is subdivided into Lions Head, Warton/Colpoy Bay, and Eramosa members. COMPOSITION: Lockport Formation is thin- to massive-bedded, fine- to medium-crystalline dolostone; Amabel Formation is thin bedded to massive, medium-crystalline dolostone with reef facies near Georgetown and on the Bruce Peninsula. THICKNESS: (Lockport/ Amabel) 10 to 130 feet (3 to 40 m). USES: both formations have been used to produce lime, crushed stone, concrete aggregate, and building stone throughout their area of occurrence, and are a resource of provincial significance. AGGREGATE SUITABILITY TESTING: PSV = 36-49, AAV = 10-17, $MgSO_4$ = 2-6, LA = 25-32, Absn = 0.4-1.54, BRD = 2.61-2.81, PN (Asphalt & Concrete) = 100-105.

Guelph Formation (Middle Silurian)

STRATIGRAPHY: exposed on the Niagara Escarpment from the Niagara River to the tip of the Bruce Peninsula, mostly present in the subsurface of southwestern Ontario. COMPOSITION: micro-crystalline to medium-crystalline, thick-bedded, soft, porous dolostone, characterized in places by extensive vuggy, porous reefal facies of high chemical purity. THICKNESS: 100 to 170 feet (30 to 52 m). USES: some areas appear soft and unsuitable for use in the production of load-bearing aggregate; this unit requires additional testing to fully establish its aggregate suitability; main use is for dolomitic lime for cement manufacture; quarried near Hamilton and Guelph.

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Salina Formation (Upper Silurian)

STRATIGRAPHY: present in the subsurface of southwestern Ontario; rarely exposed at the surface. COMPOSITION: grey and maroon shale, brown dolostone and, in places, salt, anhydrite and gypsum; consists predominantly of evaporitic rich material with up to eight units identifiable. THICKNESS: 370 to 600 feet (113 to 183 m). USES: gypsum mines at Hagersville, Caledonia, and Drumbo; salt is mined at Goderich and Windsor, and is produced from brine wells at Amherstburg, Windsor and Sarnia.

Bertie and Bass Islands Formations (Upper Silurian)

STRATIGRAPHY: Bertie Formation found in southern Niagara Peninsula; Bass Islands Formation, the Michigan Basin equivalent of the Bertie Formation, does not significantly outcrop in Ontario but is present in the subsurface in southwestern Ontario; Bertie Formation represented by Oatka, Falkirk, Scajaquanda, Williamsville, and Akron Members. COMPOSITION: medium- to massive-bedded, micro-crystalline, brown dolostone with shaly partings. THICKNESS: 45 to 160 feet (14 to 49 m). USES: quarried for crushed stone on the Niagara Peninsula at Fort Erie, Cayuga, Hagersville and Dunnville; shaly intervals are unsuitable for use as high specification aggregate because of low freeze-thaw durability; has also been extracted for lime. AGGREGATE SUITABILITY TESTING: PSV = 46-49, AAV = 8-11, $MgSO_4$ = 4-19, LA = 14-23, Absn = 0.8-2.8, BRD = 2.61-2.78, PN (Asphalt & Concrete) = 102-120.

Oriskany Formation (Lower Devonian)

STRATIGRAPHY: basal Devonian clastic unit, found in Niagara Peninsula. COMPOSITION: thick- to massive-bedded, coarse-grained, grey-yellow sandstone. THICKNESS: 0 to 15 feet (0 to 5 m). USES: has been quarried for silica sand, building stone, and armour stone; may be acceptable for use as rip rap, and well cemented varieties may be acceptable for some asphaltic products. AGGREGATE SUITABILITY TESTING: (of a well cemented variety of the formation) PSV = 64, AAV = 6, $MgSO_4$ = 2, LA = 29, Absn = 1.2-1.3, BRD = 2.55, PN (Asphalt & Concrete) = 107.

Bois Blanc Formation (Lower Devonian)

STRATIGRAPHY: Springvale Sandstone Member forms the lower portion of formation. COMPOSITION:

TION: a cherty limestone with shale partings and minor interbedded dolostones; Springvale Sandstone Member is a medium- to coarse-grained, green glauconitic sandstone with interbeds of limestone, dolostone and brown chert. **THICKNESS:** 10 to 130 feet (3 to 40 m). **USES:** quarried at Hagersville, Cayuga, and Port Colborne for crushed stone; material generally unsuitable for concrete aggregate because of high chert content. **AGGREGATE SUITABILITY TESTING:** PSV = 48-53, AAV = 3-7, $MgSO_4$ = 3-18, LA = 15-22, Absn = 1.3-2.8, BRD = 2.50-2.70, PN (Asphalt & Concrete) = 102-290.

Onondaga Formation (Middle Devonian)

STRATIGRAPHY: correlated to part of the Detroit River Group; occurs on the Niagara Peninsula from Simcoe to Niagara Falls; contains the Edgecliff, Clarence, and Moorehouse Members. **COMPOSITION:** medium-bedded, fine- to coarse-grained, dark grey-brown or purplish-brown, variably cherty limestone. **THICKNESS:** 60 to 82 feet (18 to 25 m) **USES:** quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne; high chert content makes much of the material unsuitable for use as concrete aggregate and asphaltic concrete; has been used as a raw material in cement manufacture. **AGGREGATE SUITABILITY TESTING:** (Clarence and Edgecliff Members) $MgSO_4$ = 1-6, LA = 16.8-22.4, Absn = 0.5-1.1, PN (Asphalt & Concrete) = 190-276.

Amherstburg Formation (Middle Devonian)

STRATIGRAPHY: part of Detroit River Group; correlated to Onondaga Formation in Niagara Peninsula; contains Sylvania Sandstone Member and Formosa Reef Limestone. **COMPOSITION:** bituminous, bioclastic, stromatoporoid-rich limestone and dolostone with grey chert nodules; Formosa Reef Limestone is high purity (calcium rich) limestone; Sylvania Sandstone Member is quartz sandstone. **THICKNESS:** 0 to 165 feet (0 to 50 m); Formosa Reef Limestone up to 85 feet (26 m). **USES:** cement manufacture, agricultural lime, aggregate. **AGGREGATE SUITABILITY TESTING:** PSV = 57, AAV = 19, $MgSO_4$ = 9-35, LA = 26-52, Absn = 1.1-6.4, BRD = 2.35-2.62, PN (Asphalt & Concrete) = 105-300.

Lucas Formation (Middle Devonian)

STRATIGRAPHY: part of the Detroit River Group in southwestern Ontario; includes the Anderdon Member which, in the Woodstock Beachville area, may constitute the bulk of the formation. **COMPOSITION:** light brown or grey-brown dolostone with bituminous laminations and minor chert; Anderdon Member consists of very high purity (calcium-rich) limestone. **THICKNESS:** 130 to 246 feet (40 to 75 m). **USES:** most important source of high-purity limestone in Ontario; used as calcium lime for metallurgical flux and for the manufac-

ture of chemicals; rock of lower purity is used for cement manufacture, agricultural lime and aggregate; Anderdon Member is quarried at Amherstburg for crushed stone. **AGGREGATE SUITABILITY TESTING:** PSV = 46-47, AAV = 15-16, $MgSO_4$ = 2-60, LA = 22-47, Absn = 1.1-6.5, BRD = 2.35-2.40, PN (Asphalt & Concrete) = 110-160.

Dundee Formation (Middle Devonian)

STRATIGRAPHY: few natural outcrops, largely in the subsurface of southwestern Ontario. **COMPOSITION:** fine- to medium-crystalline, brownish-grey, medium- to thick-bedded, dolomitic limestone with shaly partings sandy layers, and chert in some areas. **THICKNESS:** 50 to 100 feet (15 to 30 m). **USES:** quarried near Port Dover and on Pelee Island for crushed stone; used at St. Marys as a raw material for Portland cement. **AGGREGATE SUITABILITY TESTING:** $MgSO_4$ = 1-28, LA = 22-46, Absn = 0.6-6.8, PN (Asphalt & Concrete) = 125-320.

Marcellus Formation (Middle Devonian)

STRATIGRAPHY: subsurface unit, mostly found below Lake Erie and extending into the eastern U.S.A., pinches out in the Port Stanley area. **COMPOSITION:** black, bituminous shales. **THICKNESS:** 0 to 15 feet (0 to 5 m). **USES:** no present uses.

Bell Formation (Middle Devonian)

STRATIGRAPHY: lowest formation of the Hamilton Group, no outcrop in Ontario. **COMPOSITION:** soft blue and grey calcareous shale. **THICKNESS:** 0 to 30 feet (0 to 9 m). **USES:** no present uses.

Rockport Quarry Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group; no outcrop in Ontario. **COMPOSITION:** grey-brown, very fine-grained limestone with occasional shale layers. **THICKNESS:** 0 to 20 feet (0 to 6 m). **USES:** no present uses.

Arkona Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. **COMPOSITION:** blue-grey, plastic, clay shale with occasional thin and laterally discontinuous limestone lenses. **THICKNESS:** 15 to 120 feet (5 to 37 m). **USES:** has been extracted at Thedford and near Arkona for the production of drainage tile.

Hungry Hollow Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. **COMPOSITION:** grey crinoidal limestone and soft, fossiliferous calcareous shale. **THICKNESS:** 0 to 6 feet (0 to 2 m). **USES:** suitable for some crushed stone and fill with selective quarrying. **AGGREGATE SUITABILITY TESTING:** No data.

Widder Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: mainly soft, grey, fossiliferous calcareous shale interbedded with blue-grey, fine-grained fossiliferous limestone. THICKNESS: 0 to 45 feet (0 to 14 m). USES: no present uses.

Ipperwash Formation (Middle Devonian)

STRATIGRAPHY: upper formation of the Hamilton Group; very limited distribution. COMPOSITION: medium- to coarse-grained, grey-brown, bioclastic limestone. THICKNESS: 5 to 45 feet (2-14 m). USES: no present uses.

Kettle Point Formation (Upper Devonian)

STRATIGRAPHY: occurs in a band between Sarnia and Erieau; small part overlain by Port Lambton Group rocks in extreme northwest. COMPOSITION: black, highly fissile, organic-rich shale with minor interbeds of grey-green silty shale. THICKNESS: 0 to 200 feet (0 to

61 m). USES: possible source of fill; possible source of material for use as sintered lightweight aggregate.

Bedford Formation (Upper Devonian)

STRATIGRAPHY: lower formation of the Port Lambton Group. COMPOSITION: soft, grey shale. THICKNESS: 0 to 108 feet (0 to 33 m). USES: no present uses.

Berea Formation (Upper Devonian)

STRATIGRAPHY: middle formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: grey, fine- to medium-grained sandstone, often dolomitic and interbedded with grey shale and siltstone. THICKNESS: 0 to 197 feet (0 to 60 m). USES: no present uses.

Sunbury Formation (Upper Devonian)

STRATIGRAPHY: upper formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: black shale. THICKNESS: 0 to 66 feet (0 to 20 m). USES: no present uses.

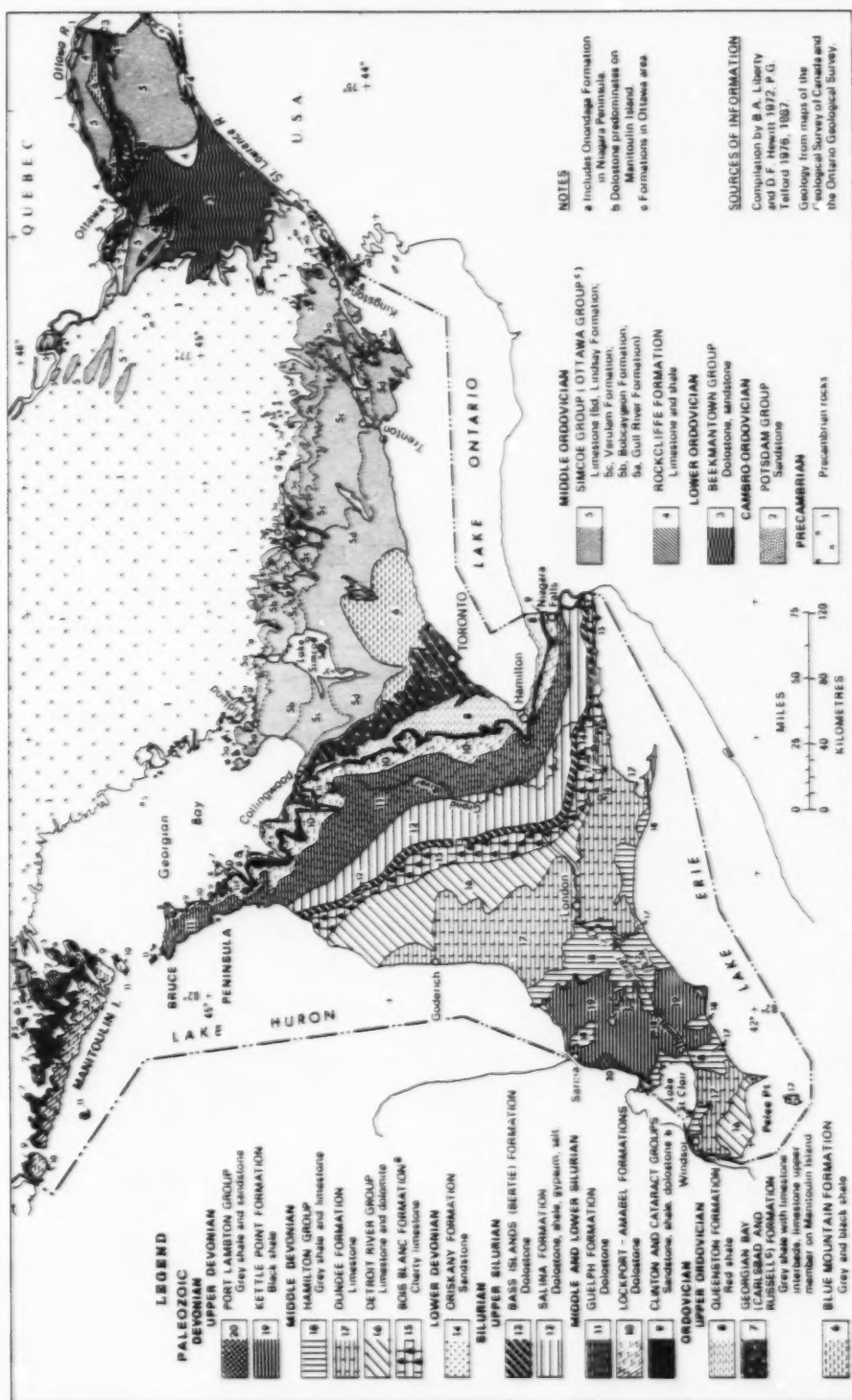


Figure D1. Bedrock Geology of Southern Ontario.

		SOUTHWESTERN ONTARIO		NIAGARA PENINSULA SIMCOE - NIAGARA FALLS	NIAGARA ESCARPMENT NORTH OF HAMILTON TO MANITOULIN ISLAND	CENTRAL ONTARIO	EASTERN ONTARIO
DEVONIAN	U	Port Lambton Gp.					
		Kettle Point Fm.					
	M	Hamilton Gp.					
		Marcellus Fm.					
		Dundee Fm.	Dundee Fm.				
			Lucas Fm.				
		Detroit River Gp.	Onondaga Fm.				
	L	Bois Blanc Fm.	Bois Blanc Fm.				
			Oriskany Fm.				
		Bass Islands Fm.	Bertie Fm.				
SILURIAN	U	Salina Fm.	Salina Fm.				
	M		Guelph Fm.	Guelph Fm. *			
			Lockport Fm.	Lockport/Amabel Fm.			
			Clinton Gp.	Clinton Gp.			
			Cataract Gp.	Cataract Gp.			
			Queenston Fm.	Queenston Fm. *	Queenston Fm.	Queenston Fm.	
	U			Georgian Bay Fm.	Georgian Bay Fm.	Georgian Bay Fm.	
				Blue Mountain Fm.	Blue Mountain Fm.	Billings Fm.	
				Collingwood Mbr.	Collingwood Mbr.	Eastview Mbr.	
					Lindsay Fm.	Lindsay Fm.	
					Verulam Fm.	Verulam Fm.	
	M				Bobcaygeon Fm.	Bobcaygeon Fm.	
					Gull River Fm.	Gull River Fm.	
					Shadow Lake Fm.	Shadow Lake Fm.	
						Rockcliffe Fm.	
	L					Oxford Fm.	
						March Fm.	
						Nepean Fm.	
CAMBRIAN						Covey Hill Fm.	



Units not present because of erosion
or non-deposition



Units in subsurface only

Gp. = Group, Fm. = Formation, Mbr. = Member

* Does not occur on Manitoulin Island

Figure D2. Exposed Paleozoic Stratigraphic Sequences in Southern Ontario
(adapted from: Bezys, R. K., and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario;
The Canadian Mining and Metallurgical Bulletin v.81, no.912, p.49-58).

Appendix E — Aggregate Quality Test Specifications

Four types of aggregate quality tests are often performed by the Ontario Ministry of Transportation on sampled material. A description of Table E1 and the specification limits for each test are given in this appendix. Although a specific sample meets or does not meet the specification limits for a certain product, it may or may not be acceptable for that use based on field performance. Additional quality tests other than the four major tests listed in this appendix can be used to determine the suitability of an aggregate. The tests are performed by the Soils and Aggregates Section, Engineering Materials Office, Ontario Ministry of Transportation.

Absorption capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate.

Los Angeles abrasion and impact test: This test measures the resistance to abrasion and the impact strength of ag-

gregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported, and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium sulphate soundness test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Petrographic examination: Individual aggregate particles in a sample are divided into categories good, fair, poor, and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

TABLE E1. SELECTED QUALITY REQUIREMENTS FOR MAJOR AGGREGATE PRODUCTS.

TYPE OF MATERIAL	TYPE OF TEST				
	COARSE AGGREGATE				FINE AGGREGATE
	Petrographic Number Maximum	Magnesium Sulphate Soundness - Max. % Loss	Absorption Maximum %	Los Angeles Abrasion Maximum % Loss	Magnesium Sulphate Soundness Maximum % Loss
Granular Base A	200	-	-	60	-
16 mm Crushed Type 'A'	160	-	-	35	-
16 mm Crushed Type 'B'	200	-	-	60	-
Granular Subbase B	250	-	-	-	-
Granular Subbase C	250	-	-	-	-
Granular Subbase D	-	-	-	-	-
Hot Mix - HL 1	100	5	1.0	15	16
Hot Mix - HL 2	-	-	-	-	20
Hot Mix - HL 3	135	12	1.75	35	16
Hot Mix - HL 4	160	12	2.0	35	20
Hot Mix - HL 8	160	15	2.0	35	20
Structural Concrete and Concrete Base	140	12	2.0	35	16
Pavement Concrete and Exposed Structure Deck	125	12	2.0	35	16

(Ministry of Transportation Forms 1002, 1003 and 1010)

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	Multiplied by	Gives	Imperial Unit	Multiplied by	Gives
LENGTH					
1 mm	0.039 37	inches	1 inch	25.4	mm
1 cm	0.393 70	inches	1 inch	2.54	cm
1 m	3.280 84	feet	1 foot	0.304 8	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	1.609 344	km
AREA					
1 cm ²	0.155 0	square inches	1 square inch	6.451 6	cm ²
1 m ²	10.763 9	square feet	1 square foot	0.092 903 04	m ²
1 km ²	0.386 10	square miles	1 square mile	2.589 988	km ²
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
VOLUME					
1 cm ³	0.061 02	cubic inches	1 cubic inch	16.387 064	cm ³
1 m ³	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m ³
1 m ³	1.308 0	cubic yards	1 cubic yard	0.764 555	m ³
CAPACITY					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	4.546 090	L
MASS					
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	31.103 476 8	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	0.453 592 37	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	907.184 74	kg
1 t	1.102 311	tons (short)	1 ton (short)	0.907 184 74	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	1016.046 908 8	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	1.016 046 908 8	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

**MAPS
NOT
FILMED**

**CARTES
OMISES**